Department of Energy
Washington, DC 20585

June 30th, 2003

High Intensity Discharge (HID) Lamps

The Department of Energy (Department) invites public review and comment on the assumptions, methodologies, and findings presented in the attached report*, Draft Framework for Determination Analysis of Energy Conservation Standards for High Intensity Discharge Lamps*, June 30th, 2003. This is the framework for the analysis that the Department is conducting to determine whether energy conservation standards for high intensity discharge lamps would be technologically feasible, economically justified and would result in significant energy savings.

The Department is interested in receiving comments and data concerning all aspects of the analysis and data in the draft report. The Department particularly requests comments on specific areas and issues raised in the attached questions (which are also embedded in the report).

This draft report makes no recommendation concerning what, if any, determination should be made or whether standards should be promulgated for HID lamps. Rather, this report presents the market and technology assessment and proposes a substitution analysis for stakeholder review. It also outlines how the Department intends to conduct the life-cycle cost assessment and national energy savings analysis. When the analysis is complete, the Department plans to conduct a public workshop presenting the results of this analysis, prior to issuing its determination.

Procedures for Submitting Comments:

DATE: Comments submitted by electronic mail will be considered timely if they are submitted by 11:59 p.m. (Eastern time) September 5, 2003. Comments submitted on paper through the United States mail or other delivery service should contain a signed original and must be received at the Department of Energy by September 5, 2003.

ADDRESSES: The *Draft Framework for Determination Analysis of Energy Conservation Standards for High Intensity Discharge Lamp*, June 30th, 2003, may be viewed on the World Wide Web at http://www.eere.energy.gov/buildings/appliance_standards/commercial/hid_lamps.html. Also, a copy is available in the Department of Energy Freedom of Information Reading Room, U.S. Department of Energy, Forrestal Building, Room 1E–190, 1000 Independence Avenue, SW, Washington, 20585-0101, telephone (202) 586-3142, between the hours of 9:00 a.m. and 4:00 p.m., Monday through Friday, except Federal holidays.

The Department encourages the submission of comments, data and information electronically to the following Internet address: hid.determination@ee.doe.gov. Submit electronic comments as a WordPerfect, Microsoft Word, Adobe PDF, or ASCII format file and avoid the use of special characters or any form of encryption. Identify comments in electronic format by the docket number EE-DET-03-001, and, wherever possible, include the electronic signature of the author. Comments submitted electronically without an electronic signature must be followed and authenticated by submitting the signed original paper document. No telefacsimiles (telefaxes) will be accepted.

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Submit written comments filed on paper to: Ms. Brenda Edwards-Jones, U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Technologies, EE-2J, 1000 Independence Avenue, SW, Washington, DC 20585-0121. Comments filed on paper should be identified by the docket number EE-DET-03-001. Please submit one signed original and a computer diskette or compact disc (CD) in WordPerfect, Microsoft Word, Adobe PDF or ASCII file format.

For Further Information Contact:

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The following is a list of the questions the Department has embedded in the attached report. This list is provided to ensure stakeholders locate all the specific areas and issues in which the Department is looking for comment. Stakeholders are invited to comment on these and all other sections of the report.

Section		Question
1.2.	High Intensity Discharge Lamp Definition	The Department requests stakeholder comments on this working definition.
2.4.2.	Mercury Vapor Lamp Product Applications	The Department welcomes comments on the product applications and identification of lamp wattages presented in Table 2-13.
2.6.	Potential Small Business Impacts	The Department requests comments on the possibility of small business impacts from HID energy conservation standards.
4.2.1.	Mercury Vapor Lamp-to-Lamp Direct Substitution	The Department invites stakeholder feedback on the direct lamp-to-lamp replacements presented in Table 4-2. Are there other lamps that the Department should consider?
4.2.2.	Mercury Vapor Lamp-to-Lamp/Ballast Substitution	The Department invites stakeholders to comment on the technologies shown and the shaded lamp/ballast combinations selected in Table 4-3. Are there other lamp/ballast combinations that the Department should consider or select?
4.2.3.	Mercury Vapor Lamp-to-Luminaire Substitution	The Department invites stakeholders to comment on the replacement luminaires shown in Table 4-4. Are there other luminaire replacements that the Department should consider or some that the Department should remove?
4.4.1.	Summary of Relevant Substitution Analyses	The Department invites stakeholders to comment on the replacement scenarios presented in Table 4-5. Are the correct types of substitutions considered for each of the product application? Are there some that the Department should drop or some that the Department should add?
5.2.	Life-Cycle Cost	The Department requests stakeholder comments on the proposed LCC calculation method.
5.2.1.	Income Tax Effects	The Department seeks input on whether income tax effects are significant enough to warrant inclusion in the LCC analysis for the Determination. The Department specifically requests information on how many firms that purchase HID equipment actually pay taxes and, if they do, what "expense" practices are utilized to depreciate the purchase costs.
5.3.1.	Equipment Cost	The Department requests that stakeholders comment on these proposed methods and provide any additional sources they believe the Department should consider.
		The Department requests stakeholder comments on how to handle this variability in discount multipliers, price, and shipment apportionment by distribution channels.
5.3.1.1.	Contractor Markup	The Department requests stakeholder comments on contractor markup and other sources for this information.
5.3.1.2.	Sales Tax	The Department requests stakeholder comments on data sources and methods for estimating and weighting sales taxes.
5.3.2.1.	Labor Times	The Department requests stakeholder comments on data sources and the proposed method for estimating labor times.
5.3.2.2.	Labor Rates	The Department requests stakeholders to suggest other sources that the Department should review for labor rates or labor classifications associated with the installation, maintenance, and operation of HID lamps.

Section	Question
5.4.1. Ballast and Lamp Lifetimes	The Department requests comments from stakeholders on lamp and ballast lifetimes. The Department also requests comments on relamping practices for HID lamps, specifically the relative likelihood of spot replacement and group replacement.
5.4.2. Discount Rate for Life-Cycle Cost	The Department requests comments from stakeholders on the discount rates it intends to use in the LCC Analysis.
5.4.3.1. Annual Electricity Consumption	The Department requests stakeholder comments on the proposed method for obtaining wattages.
	The Department requests stakeholder input on the operating hours for the luminaire types in Table 5-2.
5.4.3.2. Electricity Prices and Trends	The Department requests stakeholder comments on sources for electricity price data for the commercial, industrial, public, and residential sectors, as well as other sources that indicate future trends for these prices.
5.5. Payback Period	The Department requests stakeholder comments on the proposed calculation method for payback period.
5.6. Life-Cycle Cost Cases	The Department requests stakeholder comments on the percentage of the market that will choose each substitution technology option (Replace Lamp, Replace Lamp/Ballast, or Replace Luminaire) in Table 5-4 through Table 5-12, in response to the baseline lamp possibly becoming unavailable due to a standard. The Department will use these percentages (replacement weights) to select the most common substitution technology options for the LCC analysis.
6.1. National Energy Savings Spreadsheet	The Department requests stakeholder comments on this modeling approach to estimating national energy savings.
6.3.1. Shipments	The Department requests comments on methods for estimating forecasts of shipments and on possible scenarios.
	The Department asks stakeholders to provide their estimates of the breakdown of MV lamp shipments by wattage and product application shown in Table 6-1. The total of the percentages for each column should add to 100%.
	The Department asks Stakeholders to provide their estimates of the sectoral breakdown of MV lamp shipments for each product application and sector shown in Table 6-2. The total of the percentages for each row should add to 100%.
6.3.2. Substitution Technology Option Weights	The Department asks stakeholders to provide their estimates of the percentage of the market that will choose each Substitution Technology Option for each Product Application in Table 5-4 through Table 5-12. (Substitution Technology Option Weights within each replacement type should total 100%, as shown in the example Table 6-3.)
6.3.6. Cumulative Regulatory Burden	The Department requests comments on related regulatory actions that it should review.

Draft Framework for Determination Analysis of Energy Conservation Standards for High Intensity Discharge Lamps

Building Technologies Program
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

June 30, 2003

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LIST OF ABBREVIATIONS

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
B	Self-Ballasted Mercury
CCT	Correlated Color Temperature
CFL	Compact Fluorescent Lamp
CIE	International Commission on Illumination
CRI	Color-Rendering Index
CW	Constant Wattage Isolated Transformer
CWA	Constant Wattage Autotransformer
DC	Direct Current
EPA	Environmental Protection Agency
EPCA	Energy Policy and Conservation Act
FTA	Federal Tax Administration
HID	High-Intensity Discharge
HPS	High-Pressure Sodium
HX	High-Reactance Autotransformer
IESNA	Illuminating Engineering Society of North America
K	Kelvin (degrees)
LCC	Life-cycle cost
LLD	Lamp Lumen Depreciation
LPS	Low-Pressure Sodium
LPW	Lumens per Watt
MH	Metal Halide
MSDS	Material and Safety Data Sheet
MV	Mercury Vapor
NEMA	National Electrical Manufacturers Association
NES	National Energy Savings
NPV	Net Present Value
NRECA	National Rural Electric Cooperative Association
OCV	Open Circuit Voltage
OSHA	Occupational Safety and Health Administration
PAR	Parabolic Aluminized Reflector
PB	Payback Period
PMH	Pulse-Start Metal Halide
R	Reflector
RE	Rare-Earth (phosphor)
RUS	Rural Utilities Service of the U.S. Department of Agriculture
SPD	Spectral Power Distribution
TCLP	Toxicity Characteristic Leaching Procedure
UV	Ultra-Violet

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1. Introduction

The Department of Energy ("the Department") is preparing a Determination Analysis on High-Intensity Discharge (HID) lamps. The Department will analyze one or, if necessary, other possible standard levels in the HID lamp Determination Analysis. The initial focus is on a possible standard level at efficacies higher than those typical of current mercury vapor HID lamps. The purpose of the Determination Analysis is to provide the basis for ascertaining if mandatory energy conservation standards are technologically feasible and economically justified, and would result in significant energy savings. The Secretary of Energy will decide these issues after the Determination Analysis is complete. Presently, the Department is publishing this Draft Framework for Determination Analysis of Energy Conservation Standards for HID lamps to obtain early input from stakeholders on the work completed, the methodology to gather input data, the proposed Life-Cycle Cost (LCC) and National Energy Savings (NES) models, and the strategy for further action on the Determination Analysis.

If the Secretary decides that standards are warranted, i.e. are technologically feasible and economically justified and would result in significant energy savings, the Department will develop a test procedure and then initiate a rulemaking to determine what the appropriate standard should be.

This draft framework contains draft sections of the Market Assessment, Technology Analysis and Substitution Analysis. These sections explore questions such as:

- Market Assessment – How large is the HID lighting market? How are HID lamps specified (i.e., which products will service a particular job)? What are the distribution channels servicing the market? What are the product applications the Department will use in this analysis?
- Technology Analysis – What are the HID lamp technologies and their performance characteristics? What are the ballasts that operate them?
- Substitution Analysis – If an efficacy standard results in the removal of the mercury vapor lamp from the market, which technologies could replace mercury vapor? Which are the high-volume mercury vapor markets that the Department should consider when it conducts its LCC analysis?

This draft framework also outlines the methodology for the LCC and Payback Period Analysis and the NES Analysis. These two sections incorporate:

- LCC and Payback Period Analysis – What LCC model will the Department use for the analysis? What LCC and payback period calculation methods will the model use? What are the inputs to the model? How will the Department gather data to provide these inputs?
- NES Analysis – What NES model will the Department use for the analysis? What NES and Net Present Value calculation methods will the model use? What Base Case (no HID lamp standards) and Standards scenarios will the Department analyze? What are the inputs to the model? How will the Department gather data to provide these inputs?

To facilitate review of the draft framework presented in this document, the Department provides in Appendix A (Glossary of Terms) definitions for terminology relating to lighting and HID technology.

1.1. Legal Authority

The Department is conducting a Determination Analysis under the authority of Section 346 of the Energy Policy and Conservation Act (EPCA) (42 U.S.C. 6317), the relevant portion of which reads as follows:

> Sec. 346. Energy conservation standards for high-intensity discharge lamps, distribution transformers, and small electric motors
> (a) High-intensity discharge lamps and distribution transformers
> (1) The Secretary shall, within 30 months after October 24, 1992, prescribe testing requirements for those high-intensity discharge lamps and distribution transformers for which the Secretary makes a determination that energy conservation standards would be technologically feasible and economically justified, and would result in significant energy savings.
> (2) The Secretary shall, within 18 months after the date on which testing requirements are prescribed by the Secretary pursuant to paragraph (1), prescribe, by rule, energy conservation standards for those high-intensity discharge lamps and distribution transformers for which the Secretary prescribed testing requirements under paragraph (1).
> (3) Any standard prescribed under paragraph (2) with respect to high-intensity discharge lamps shall apply to such lamps manufactured 36 months after the date such rule is published.

Thus, the Secretary of Energy will make a determination whether energy conservation standards for HID lamps are technologically feasible and economically justified, and would result in significant energy savings. If the Secretary finds that energy conservation standards are warranted, the Department will commence work on a test procedure. Following the issuance of the test procedure, the Department will initiate a standards rulemaking process to establish energy efficiency standard (or standards) for HID lamps.

1.2. High Intensity Discharge Lamp Definition

EPCA does not define "high-intensity discharge lamps." Therefore, the Department developed the following definition based on existing definitions used by the American National Standards Institute (ANSI) and the Illuminating Engineering Society of North America (IESNA).[1]

> High-intensity discharge (HID) lamp means an electric discharge lamp in which the arc tube wall temperature stabilizes a light-producing arc, and the arc tube wall loading is

[1] Complete definitions of HID lamps from the ANSI and IESNA sources appear in Appendix B of this report.

in excess of 3.0 watts per square centimeter. The following are examples of lamps that, when they meet these criteria, are considered HID lamps:

1. A self-ballasted lamp, i.e. a lamp which contains the ballast within the lamp.
2. A lamp in which radiation from mercury produces the major portion of the light. This type of lamp is commonly referred to as a mercury vapor lamp, and it typically operates at a partial vapor pressure in excess of 1.013×10^5 pascals (760 torr).
3. A lamp in which radiation of metal halides and their products of dissociation in combination with metallic vapors such as mercury produces the major portion of the light. This type of lamp is commonly referred to as a metal halide lamp.
4. A lamp in which radiation from sodium vapor produces the major portion of the light. This type of lamp is commonly referred to as a high-pressure sodium lamp, and it typically operates at a partial pressure equal to or greater than 6.67×10^3 *pascals (50 torr).*

Due to a lower level of arc tube wall loading, low-pressure sodium (LPS) lamps are not HID lamps. Therefore, this draft framework does not include LPS lamps in its scope nor in the HID lamp definition. However, it is important to note that the lighting industry generally treats LPS lamps as HID lamps due to commonality in construction, operational characteristics, and application.

The Department requests stakeholder comments on this working definition.

2. Market Assessment

When conducting a Determination Analysis, the Department gathers information on the state of the industry and the market characteristics of the product concerned. The Department uses these data as some of the inputs to the LCC analysis and the NES estimate, which, in turn, the Secretary uses to determine whether to proceed with a rulemaking.

This section reports on the quantitative and qualitative findings of the market assessment including: shipment estimates, market structure, installations and applications, and non-regulatory efficiency improvement initiatives.

2.1. Shipment Estimates

The HID lamp market in the United States is approximately a 390 million-dollar-per-year industry (NEMA, 2003c). Annual HID lamp sales exceed 30 million units (NEMA, 2003a). Nationally, HID lamps as a light source consumed 130 terawatt-hours, or approximately 3.7%, of total US electricity generated in 2001 (NCI, 2002).

Three primary types of light sources characterize the HID lighting market: high-pressure sodium (HPS), mercury vapor (MV), and metal halide (MH). Technical information on HID technologies, including details about their performance, light characteristics, operating life, and other information, is provided in Section 3, the Technology Assessment.

2.1.1. Energy Use by Sector

Table 2-1 presents the energy consumption for lighting in four general sectors: three building sectors (residential, commercial and industrial) and one called ‘outdoor stationary’ that incorporates lighting installations, such as street and area lighting, parking lots and garages, airport runway systems, traffic signals, and billboard lighting (NCI, 2002). However, the outdoor stationary sector does not represent all outdoor stationary luminaires. In this study, the three building sectors also include some outdoor stationary lighting, where the circuit for the outdoor luminaires is tied to the circuit for a building (e.g., architectural lighting, office parking lot lighting, residential security lighting) (NCI, 2002).

Table 2-1: U.S. National Energy Use for Lighting by Sector

Sector	Electricity Use per Building (kWh/yr)	Number of Buildings	Site Energy (TWh/yr)	Primary Energy[2] (quads)	Percent of Total
Residential	1,946	106,989,000	208	2.2	27%
Commercial	83,933	4,657,000	391	4.2	51%
Industrial	475,063	227,000	108	1.2	14%
Outdoor Stationary	n/a	n/a	58	0.6	8%
Totals			765	8.2	100%

Source: Lighting Market Characterization, NCI, 2002.

Table 2-1 presents the estimate of total lighting electricity consumption in the United States as 765 Terawatt-hours (TWh), or 8.2 quadrillion British thermal units (quads) of primary energy. To put this into a broader context, the United States used approximately 98.3 quads in 2001, of which more than a third (about 37 quads) was used to generate electricity (EIA, 2002a). Thus, lighting accounted for approximately 8.3% of national primary energy consumption, or about 22% of the total electricity generated in the U.S., in 2001.

Figure 2-1 shows the total lighting energy consumption for the four sectors, and illustrates the amounts of energy used by the various lighting technologies. From this figure, the significance of the HID technology and its dominance in the outdoor stationary sector is evident.

[2] Primary energy refers to the total energy required to generate and supply electricity to the customer site. The factor used in the NCI, 2002 study to convert the site-use electrical energy to primary energy consumed at the generating power plant was 10,768 BTU/kWh for the year 2000. This conversion factor incorporates generation, transmission, and distribution losses on an average basis for the U.S. Note that the conversion efficiency varies from year to year, depending on the mix of electrical generating power plants used in a given year.

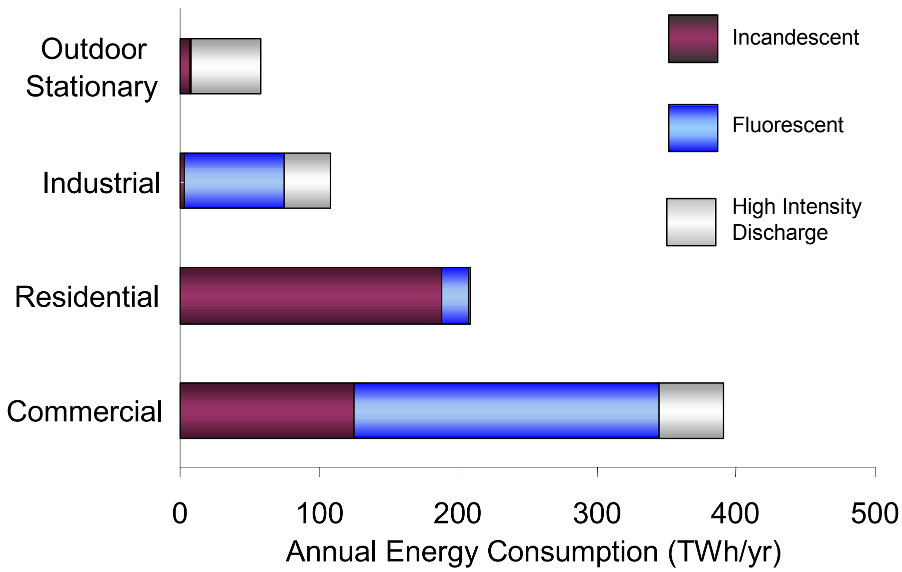

Figure 2-1: Shares of Sectoral Energy Use by Lighting Technology
Source: Lighting Market Characterization, NCI, 2002.

The outdoor stationary lighting energy consumption is primarily from HID sources, which account for 87% (50 TWh/year or 0.5 quads) of the outdoor stationary's 58 TWh/year of lighting electricity use. The industrial sector operates a large share of HID sources, which constitute 31% (33 TWh/year or 0.36 quads) of this sector's 108 TWh/year of lighting-related energy consumption. The commercial sector also has a reasonably large share of HID light sources, which constitute approximately 12% (46 TWh/yr or 0.5 quads) of the annual 391 TWh/year of electricity use in this sector. In the residential sector, where 90% of lighting energy use is consumed by incandescent technologies, HID sources account for less than 1% (0.7 TWh/year or 0.1 quads) of the energy consumption. Across all four sectors, HID sources consumed a total of 130 TWh/year (1.4 quads) in 2001. This amounts to approximately 17% of the annual electricity consumption for lighting.

Table 2-2 presents the estimated installed base of HID luminaires in the U.S. by technology and sector (NCI, 2002). HPS is estimated to be the most prevalent HID luminaire, with a market share nearly twice that of MV. HPS is the leading source in the outdoor stationary sector, while MH dominates in the commercial and industrial sectors. In the residential sector, MV is the most prevalent technology, with nearly three times more installations than HPS. The total estimated installed base of HID luminaires in the U.S. for 2001 was approximately 101 million.

Table 2-2. Installed Base of High Intensity Discharge Luminaires in the U.S. by Sector

HID Light Source	Residential	Commercial	Industrial	Outdoor Stationary	Total
Mercury vapor	3,103	5,401	1,750	12,146	22,400
Metal halide	-	19,378	10,706	4,726	34,809
High pressure sodium	1,204	5,814	2,694	34,347	44,058
Total	4,307	30,593	15,150	51,219	101,267

Source: Adapted from Lighting Market Characterization, NCI, 2002.

Table 2-3 shows the electricity consumption of each lamp type as a percentage of total HID electricity consumption (approximately 130 TWh/yr) as illustrated in Figure 2-1 (NCI, 2002). HPS is prominent in the outdoor stationary sector and MH is the largest electricity consumer in the commercial and industrial sectors. Overall, the residential sector accounts for approximately one-half of 1% of HID energy consumption.

Table 2-3: Distribution of High Intensity Discharge Lighting Electricity Consumed

HID Lamp	Residential	Commercial	Industrial	Outdoor Stationary	Total
Mercury vapor	0.4%	5%	3%	9%	17%
Metal halide	-	27%	19%	4%	50%
High pressure sodium	0.1%	4%	4%	24%	32%
Total	0.5%	36%	26%	37%	100%

Source: Adapted from Lighting Market Characterization, NCI, 2002.

2.1.2. High Intensity Discharge Lamp Shipment Estimates

National Electrical Manufacturers Association (NEMA) members who are HID lamp manufacturers are responsible for 100% of domestic HID lamp production, and over 90% of national HID lamp sales (NEMA, 2003a). Table 2-4 presents NEMA estimates of annual HID lamp shipments to the U.S. lighting market, broken down into the three HID lamp types (LPS shipments were not provided).

NEMA also provided shipment estimates of non-NEMA companies operating in the U.S. market. It prepared these estimates by deducting NEMA-member HID lamp imports from total HID imports reported by the Census Bureau. However, the data that NEMA supplied to the Department for non-NEMA shipments only dates back to 1999 for HPS and MH, and to 1993 for MV. Thus, the non-NEMA imports shown in the gray-shaded boxes of Table 2-4 are estimates (in millions) that the Department made by calculating an average of the proportion of NEMA imports to total imports reported by the Census Bureau for the given years.

Table 2-4: U.S. Shipments of High Intensity Discharge Lamps

Year	High Pressure Sodium		Metal Halide		Mercury Vapor	
	NEMA (incl. NEMA imports)	Non-NEMA Imports	NEMA (incl. NEMA imports)	Non-NEMA Imports	NEMA (incl. NEMA imports)	Non-NEMA Imports
1990	7.4	0.2	5.7	0.6	6.2	0.6
1991	8.2	0.2	5.5	0.6	4.5	0.7
1992	8.8	0.1	6.4	0.6	4.7	0.5
1993	9.7	0.1	7.3	0.6	4.6	0.8
1994	10.6	0.1	8.7	0.6	4.8	0.7
1995	10.8	0.2	10.5	0.6	4.5	0.9
1996	11.9	0.2	11.6	0.3	4.4	0.7
1997	11.9	0.2	13.2	0.4	3.5	1.0
1998	12.2	0.2	15.4	0.3	2.8	2.0
1999	12.6	0.9	18.1	0.8	2.7	2.1
2000	11.5	0.3	18.1	1.4	1.8	1.4
2001	11.5	0.0	18.3	0.3	2.6	0.8
2002	11.7	0.0	18.8	0.4	2.4	0.5

Note: Shaded cells are estimates. Source: NEMA, 2003a; Census, 2003a.

As shown in Table 2-4, the market for HPS appears to have reached a plateau at approximately 12 million units per year for the last seven years. MH shipments are growing, having more than tripled in market share over the last 12 years, while MV shipments have declined by nearly 60% over that same time period.

Table 2-5 presents the number of units imported (in millions) for the U.S. lighting market and the percentage of those imports attributable to NEMA members. The lamp imports include both the NEMA and non-NEMA members. On average, NEMA member imports calculated from 1990 to 2002 were: 90% of HPS, 76% of MH, and 33% of MV. Their share has been steadily growing, reaching 100% of HPS, 84% of MH, and 71% of MV by 2002.

Table 2-5: Total Imported High Intensity Discharge Lamps and Member Percentages

Year	High Pressure Sodium		Metal Halide		Mercury Vapor	
	Imports	% NEMA	Imports	% NEMA	Imports	% NEMA
1990	1.82	-	-	-	0.82	-
1991	1.56	-	-	-	1.09	-
1992	1.22	-	-	-	0.76	-
1993	1.27	-	-	-	0.78	0%
1994	0.76	-	-	-	0.77	9%
1995	2.33	-	-	-	1.23	27%
1996	1.96	-	1.46	-	0.92	24%
1997	2.24	-	1.66	-	1.71	42%
1998	1.96	-	1.28	-	2.46	19%
1999	3.45	74%	1.92	58%	3.03	31%
2000	2.22	86%	4.72	70%	2.8	50%
2001	2.03	100%	3.59	92%	1.79	55%
2002	1.69	100%	2.47	84%	1.75	71%
Average:	-	90%	-	76%	-	33%

Source: Census, 2003a; NEMA, 2003a.

Figure 2-2 and Figure 2-3 illustrates the annual shipments and market share by source type (MV, MH, and HPS). From these figures, the decline in MV shipments is evident, in contrast with the HPS and MH shipments. Figure 2-2 plots the total shipments, domestic and imports, by HID lamp type from 1990 to 2002. The figure also plots the sum of the three HID sources annually to track the growth of each type with respect to each other.

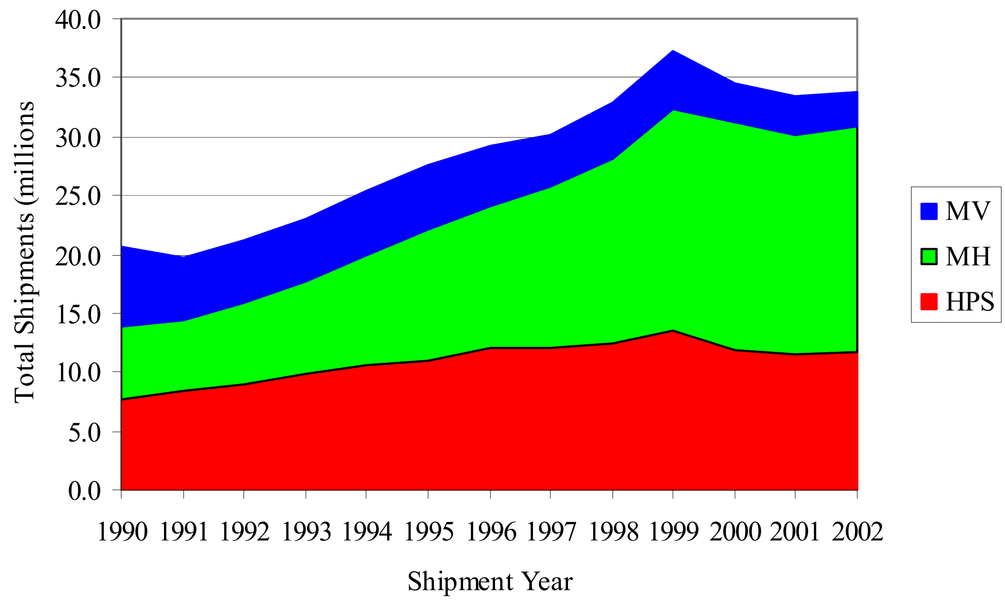

Figure 2-2: Annual High Intensity Discharge Lamp Shipments for the United States

Source: NEMA, 2003a.

Figure 2-3 presents annual shipments data as a percent of total shipments in a given year. In this figure, the decline in MV's share of the market is even more evident, since its shrinking proportion contrasts with the expanding MH market share.

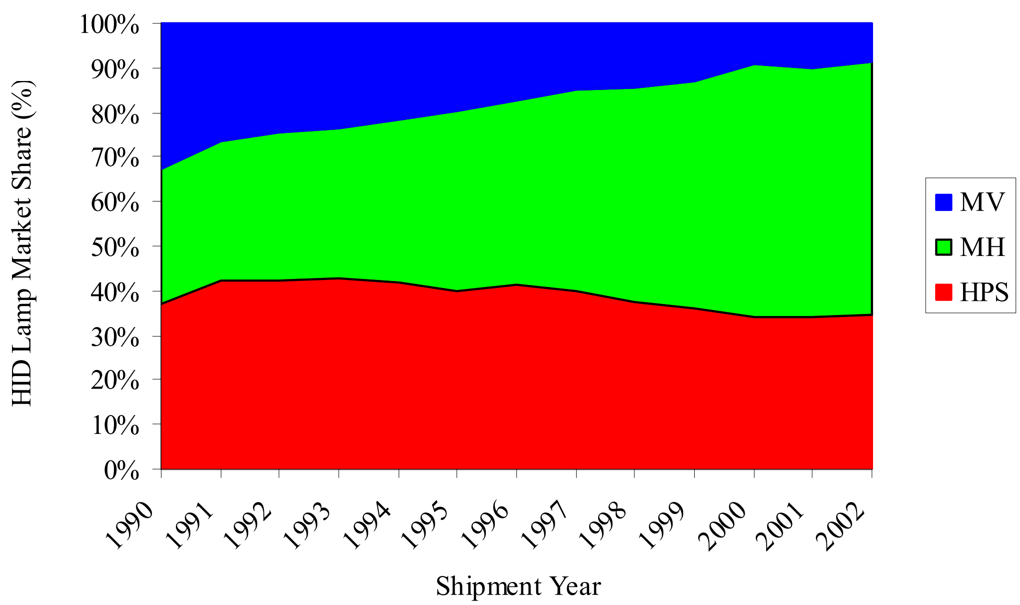

Figure 2-3: Percentage Market Share of Each High Intensity Discharge Lamp Type

Source: NEMA, 2003a.

National shipments of HPS lamps appear to have leveled off, after a strong growth period in the early 1990s. HPS lamps are a mature technology, having been commercially available for more than 30 years. Similarly, the growth in MH lamp shipments has slowed, although it is the only HID lamp that has increased its market share in the last five years. Industry continues to invest in MH technology, and improvements in this technology will further enable it to compete in applications, which typically use non-HID sources. Examples of these performance improvements (which are discussed in section 3 of this draft framework, the Technology Assessment) include pulse-start technology and the development of a ceramic arc tube. These and other improvements have lengthened the operational life of MH technology, enabling it to compete directly with HPS and MV. Additionally, the introduction of the ceramic arc tube and the improvement in the color-rendering index (CRI) have enabled the MH lamp to compete with non-HID sources, such as fluorescent and incandescent, in certain applications.

The MV lamp market, in contrast to MH, shows a gradually decreasing market share. MV technology has been commercially available for more than 60 years, and now the market may be moving to other light sources, which offer greater efficiency and improved light quality. However, the rate of market-share decrease for MV has slowed over the last twelve years, and the data suggest that this slowing of the rate of decline will continue. The low initial first cost and long operating life are attributes of MV lamps that may slow their retirement from the market.

In response to the Department's inquiry about principal MV lamp wattages, NEMA provided a table disaggregating wattages shipped in 1993 and 2001. Table 2-6 displays that information.

Table 2-6: Mercury Vapor Shipments by Wattage

Wattage	Description	1993		2001	
		Shipments	Percent Share	Shipments	Percent Share
100	Mogul	333,696	8%	243,000	9%
175	Mogul	2,778,266	63%	1,612,000	60%
250	Mogul	277,543	6%	161,000	6%
400	Mogul	578,094	13%	326,000	12%
1000	Mogul	125,493	3%	69,000	3%
All	Medium	253,000	6%	226,000	8%
All	Others incl. self-ballasted	50,000	1%	29,000	1%
Total		4,396,092	100%	2,666,000	100%

Source: NEMA, 1995; NEMA, 2003a.

The data show a 39% decline in total shipments between 1993 and 2001. Yet, the proportion of wattages within those total shipments remained relatively constant over that eight time period. This suggests that MV lamp shipments are not migrating toward a few particular wattages over time; rather, they are maintaining their respective proportions in the declining market. Furthermore, the data in Table 2-6 show that the 175-watt mogul base accounts for approximately 60% of the total MV shipments. The sales of this lamp are five times greater than those of the next closest high-volume MV wattage (400 watt mogul), which constitute only 12%.

2.1.3. High Intensity Discharge Fixture Shipment Estimates

Starting in 1962, the Department of Commerce's Census Bureau, for its Current Industrial Reports program, began conducting surveys to provide periodic assessments of production and shipment of various electric lighting fixtures. The Census Bureau tracks physical shipments of all products sold, transferred to other establishments of the same company, or shipped on consignment, whether for domestic sale or export (Census, 2001).

The Census Bureau divides HID fixtures into three product types: commercial, industrial and outdoor. The Census Bureau bundles residential HID fixtures with all outdoor-type fixtures. Although the Census Bureau classifies fixtures by sector-type, this does not necessarily imply exclusive sale or use to one of those sectors. Rather, this classification is based on which sector has the largest usage of each type of fixture. For example, a fixture classified as an "industrial type" fixture may not be sold exclusively to the industrial sector - it may also have some commercial applications.

Figure 2-4 shows the total number of HID fixture shipments by year for the period from 1996 to 2001, by Census Bureau fixture type. The outdoor-type fixture shipments represent the majority of all shipments for HID light sources, constituting approximately two-thirds of all HID lighting fixture shipments in 2001. Although the outdoor-type fixtures include residential-type fixtures , the contribution of the residential sector is insignificant in comparison to the other sectors(see Figure 2-1 and Table 2-2).

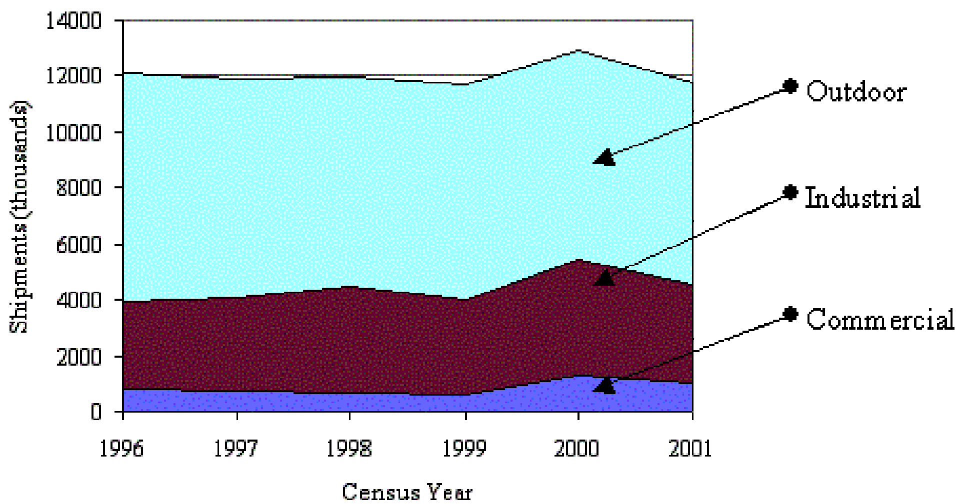

Figure 2-4: Total Shipment of High Intensity Discharge Fixtures by Fixture Type

Source: Census, 2001.

The following sub-sections present a more detailed breakdown of the shipments by sectoral fixture type.

2.1.3.1. Commercial-type High Intensity Discharge Fixtures

Figure 2-5 shows the total shipments of HID commercial-type fixtures from 1996 to 2001. Insulation contact (IC) fixtures can be in direct contact with ceiling insulation. The non-

IC fixtures require a 3-inch-minimum clearance from the ceiling insulation. A fixture is designated as 'enclosed' if a lens, louver or other cover is used to shield the lamp from the environment. Direct fixtures include all surface- or pendant-mounted fixtures that provide direct illumination, while indirect fixtures include pendant- or wall-mounted fixtures that provide indirect illumination.

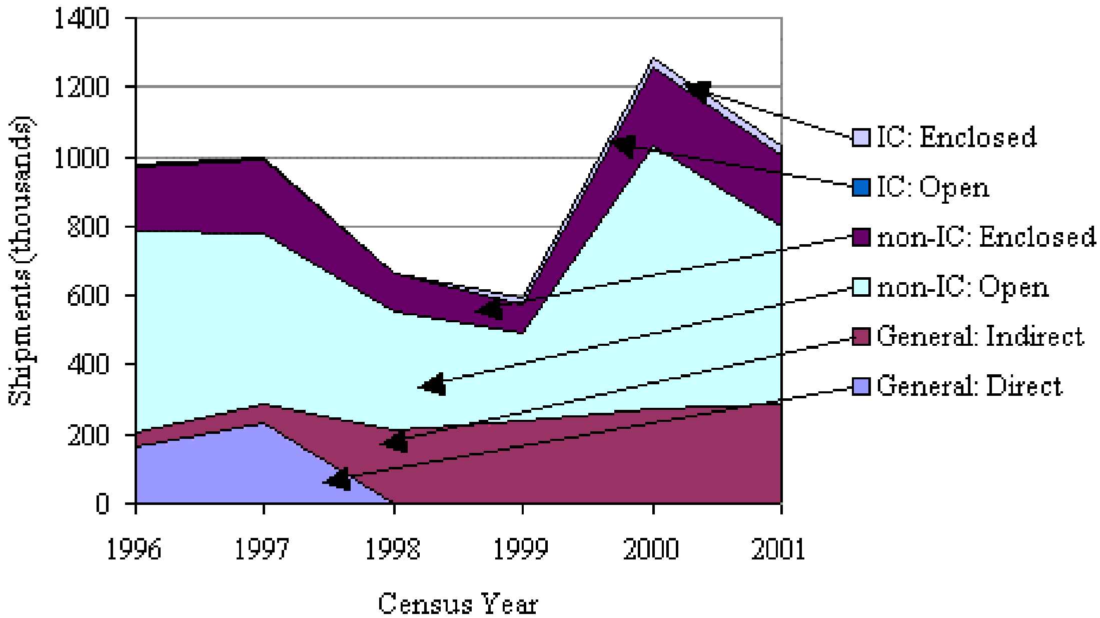

Figure 2-5: Commercial-type High Intensity Discharge Fixture Shipments

Source: Census, 2001.

There has been an extremely low volume of shipments of IC enclosed and IC open fixtures over the six-year period shown in Figure 2-5. Conversely, non-IC fixtures were responsible for the majority of commercial-type shipments for all six years shown. In 2001, non-IC open fixtures accounted for approximately 59% of commercial-type HID fixture shipments. General indirect fixtures commanded 19% of the market, and non-IC enclosed fixtures were responsible for 17%. General direct fixtures were popular in 1996 and 1997, but have had little market share in the last four years.

2.1.3.2. Industrial-type High Intensity Discharge Fixtures

Figure 2-6 shows the total shipments of industrial-type HID fixtures from 1996 to 2001. The Census Bureau tracks industrial-type fixtures in three classifications: general open fixtures, general enclosed fixtures, and parking garage fixtures. The parking garage fixtures include only fixtures that are specifically designed for this application. The general enclosed and open fixtures include fixtures with integrally mounted and remote ballasts. The enclosed designation is given to fixtures with a lens, louver or other cover that provides a barrier between the lamp and the environment.

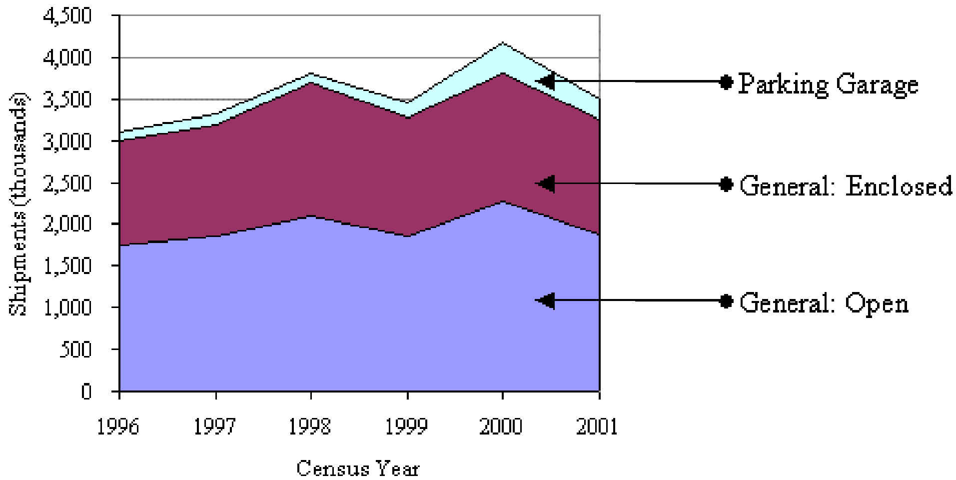

Figure 2-6: Industrial-type High Intensity Discharge Fixture Shipments

Source: Census, 2001.

For industrial-type HID fixtures, the general open-type fixture constitutes over half of all industrial-type fixture shipments. The general enclosed fixtures are second, accounting for approximately 30% of the market. The parking garage fixtures command approximately 5% of shipments. Although there is some limited variation over the six-year period presented, the proportions of these three industrial-type fixtures are relatively constant.

2.1.3.3. Outdoor-type High Intensity Discharge Fixtures

The third HID fixture type reported by the Census Bureau is the outdoor-type. Figure 2-7 shows the shipments of outdoor-type HID fixtures for the years 1996 to 2001. Wall packs include all fixtures that are installed on the exterior wall of a building. For this classification, it is important to note that the Census Bureau does not differentiate HID wall packs from incandescent wall packs. The large area fixtures are arm-mounted on a 20-to-60-foot pole. Post-top fixtures are mounted directly on top of a post less than 20 feet in height. Bollards are fixtures that have the appearance of a short thick post. Small area fixtures are the same as the large area fixtures, except the pole height is less than 20 feet. Sports lighting fixtures are designed specifically for illuminating athletic facilities. Precise optics and specialized mounting gear to acquire the critical distribution and glare control characterize these fixtures. General flood fixtures include all other integrally mounted and remote ballasted fixtures in the outdoor-type category. The tunnel fixtures comprise all roadway (street and highway) fixtures, including fixtures designed to light tunnels and bridges. The popular outdoor-type HID fixture referred to as a “cobra head” is also included in the Census Bureau’s enclosed tunnel fixture classification.

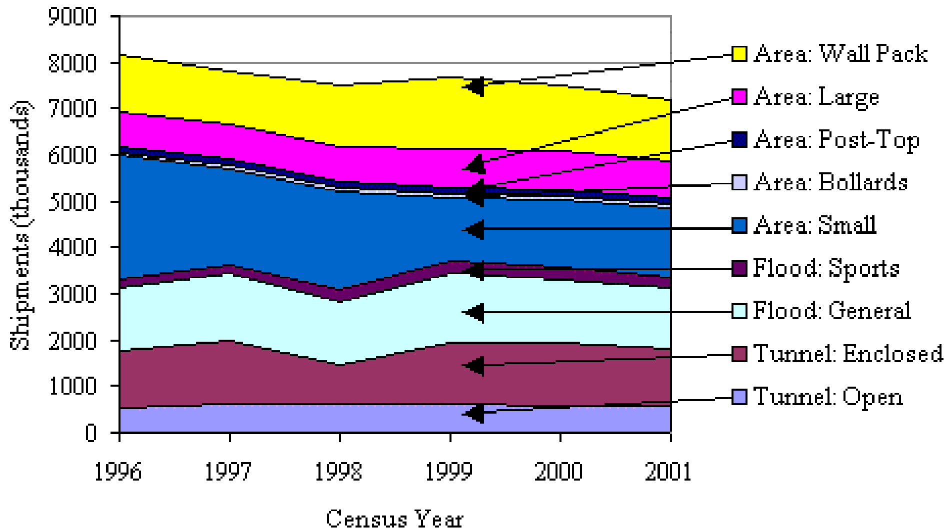

Figure 2-7: Outdoor-type High Intensity Discharge Fixture Shipments
Source: Census, 2001.

Figure 2-7 shows an overall decline in fixture shipments. The Department believes this decline results from market saturation, rather than a shift away from outdoor-type HID fixtures. The outdoor-type fixture market is reaching an equilibrium point where growth in this part of the market is leveling out, and new fixture installations are becoming less frequent. The four consistently dominant fixture types in this group are area wall packs, small area (poles less than 20 feet), general flood and tunnel enclosed. Together, these four classifications constitute more than 80% of the shipments between 1996 and 2001.

2.2. Market and Structure

NEMA members represent 100% of the domestic market production for HID lamp sources (NEMA, 2003a). Furthermore, as Table 2-5 shows, NEMA members are responsible for over 85% of the import market, and that share is growing.

2.2.1. Manufacturers of High Intensity Discharge Lamps, Luminaires, and Ballasts

Six manufacturers listed in Table 2-7 make up the NEMA membership for HID lamp manufacturing. These six members are responsible for the entire domestic production of HID lamps (NEMA, 2003a). The six firms, like many of NEMA's members, may have manufacturing facilities located overseas, and bring their products into the U.S. as imports. Consequently, the Census Bureau's report on foreign imports may overstate the influence of foreign manufacturers on the HID lamp market (demonstrated by Table 2-4 and Table 2-5).

Table 2-7: High Intensity Discharge Lamp Manufacturers

Company Names
EYE Lighting International of N.A.
GE Lighting
OSRAM Sylvania
Philips Lighting Company
Ushio America, Inc.
Venture Lighting

Source: NEMA 2003b.

Table 2-8 presents the NEMA member companies that manufacture HID ballasts. Electronic ballasts for HID lamps are relatively new, so the list of manufacturers is shorter. The magnetic ballast market is more established and has a greater number of companies participating.

Table 2-8: High Intensity Discharge Ballast Manufacturers

Electronic Ballasts	Magnetic Ballasts
Advance Transformer Company	Advance Transformer Company
GE Lighting	Cooper Lighting
Universal Lighting Technologies	EYE Lighting International of N.A.
Venture Lighting Power Systems	Genlyte Thomas Group LLC
	Holophane
	Killark Electric Manufacturing Company
	OSRAM Sylvania
	Universal Lighting Technologies

Source: NEMA, 2003b; Company websites of those listed, 2003.

Luminaires may include any technology, including incandescent, HID, LPS, and fluorescent lighting, as their primary integrated light source. NEMA structures its HID lamp industry into manufacturers of adverse location lighting, indoor lighting, lamp-holders, outdoor lighting, and remote illumination. Although HID light sources are also used in adverse and remote illumination applications, those applications represent a small niche and do not hold a significant share of the typical HID market. Therefore, the list in Table 2-9 represents all NEMA manufacturers of general-purpose HID luminaires.

Table 2-9: High Intensity Discharge Luminaire Manufacturers

Indoor HID	Outdoor All
American Electric Lighting	American Electric Lighting
Cooper Crouse-Hinds	Cooper Crouse-Hinds
Cooper Lighting	Cooper Lighting
EGS Electrical Group	EGS Electrical Group
EYE Lighting International of N.A.	Ericson Manufacturing Company
GE Lighting	GE Lighting
Genlyte Thomas Group LLC	Genlyte Thomas Group LLC
Holophane	Holophane
Hubbell Incorporated	Hubbell Incorporated
Indy Lighting, Inc	Indy Lighting, Inc
Juno Lighting Inc.	Juno Lighting Inc.
Killark Electric Manufacturing Company	Killark Electric Manufacturing Company
Lightolier	Lightolier
Lithonia Lighting	Lithonia Lighting
National Cathode Corp.	Prescolite
Prescolite	Progress Lighting
Progress Lighting	R. Stahl Inc.
R. Stahl Inc.	Simkar Corporation
Ushio America, Inc.	Ushio America, Inc.

Source: NEMA, 2003b; Company websites of those listed, 2003.

The HID lamp market is highly concentrated. Similarly, a few manufacturers dominate the domestic ballast and luminaire markets. The top three manufactures of HID luminaires in the U.S. are Cooper Lighting, Lithonia Lighting and Genlyte Thomas Group. Together, these three companies represent over 50% of all domestic production of these fixtures (NEMA, 2003a).

2.2.2. Distribution Channels

The distribution channels for the HID lighting market are shown in Figure 2-8. The structure of this figure is relevant for all end-use sectors (residential, commercial, industrial and public sector); however, the volume of product going through the various channels will vary. The Department adapted this model for the lighting distribution channels—introduced by Sardinsky in 1995 (LBNL, 1997)— and updated it, using manufacturer literature and market research on various lighting specifiers, to reflect the current HID lamp market. HID lamp manufacturers sell products through six categories of distributors. The specialty, local and regional retailers primarily serve the residential sector. The mail order and electrical distributor network are the principal outlets used by the commercial, industrial and public sector lighting markets. The national accounts serve all sectors.

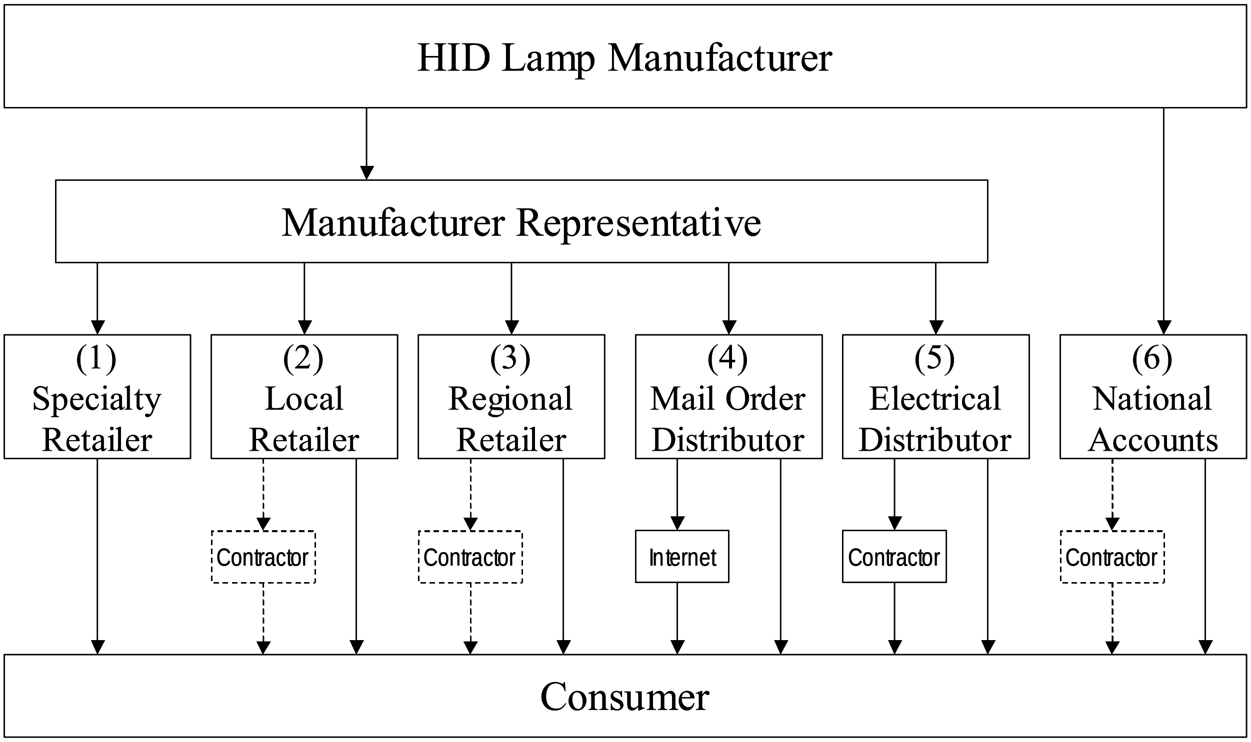

Figure 2-8: Lighting Market Distribution Channels

The specialty distributor is a broad distribution category that includes a range of constituents, including numerous independently owned specialty lamp retailers. However, as an HID lamp distribution channel, it represents a very small share of the total market for HID lamps.

Local retailers are the larger retail outlets, such as local hardware stores and supermarkets. This is also a limited outlet for HID products that primarily serves the residential sector. Although product availability is limited, some local and small contractors may opt to purchase HID lamps through these channels.

Regional retailers are the larger chain stores that have multiple locations. Similar to the local retailers, they will usually offer a limited selection of HID lamp products tailored to the residential sector. Once again, contractors have very limited contact with this channel.

Mail-order distribution is another major distribution channel. Although these distributors stock products used in all sectors, lamp availability through this channel is typically limited to high-volume items. Smaller businesses and contractors are the primary end-users for these distributors. However, the Internet is expanding the end-user base for these outlets, and enabling them to adapt more quickly to end-user needs.

Large electrical-equipment distributors handle the bulk of the HID lamp shipments . They effectively operate as a wholesale clearinghouse for the HID lamp industry. Often, a contractor will operate as a middleman between the end-user and distributor. Building management companies, maintenance contractors, developers, municipalities and utilities purchasing street/roadway lamps, and other such entities purchase either directly from an electrical equipment distributor or through a contractor.

The sixth and last major channel of distribution is through the national accounts. Lamp manufacturers sell some products through large national retailers such as Wal-Mart, Sears and do-it-yourself centers such as Home Depot. Large maintenance companies and other national businesses may also purchase lamps directly from the manufacturers. However, product availability through these outlets is limited to high-volume (commodity) HID products.

The advent of the Internet has created a new opportunity that could have a significant impact on all distribution channels and sectors. In response to the growing base of Internet users, manufacturers have created new online databases that list product offerings and links to various distribution channels for purchase. Although the references are primarily linked to mail-order distribution houses, other links to walk-in retailers are also available. For end-users interested in accessing products, these new online sources and distributors offer an alternative to the traditional channels of large retailers and specialty stores. Many of these websites incorporate "design centers" that help the end-users match lamps with their needs, much like a knowledgeable specifier or sales representative would do. The total impact on shipments for this industry is small at this time.

2.2.3. Decision Makers

After the initial installation of a luminaire is complete, purchase of replacement lamps becomes essentially a maintenance issue. Therefore, the decision-maker decides on the light source prior to installation. The specifiers who determine which light source to install are the electrical contractors, architects, lighting designers, electrical engineers, building owners, homeowners, building maintenance personnel, municipal officials, state officials (highway departments), and corporate officials who select fixtures for their properties. In addition, electrical distributors and manufacturers may also influence the choice of light source.

2.2.3.1. Residential Decision Makers

For the residential sector, the interaction between the builder (or homeowner) and the other stakeholders (i.e., designer, contractor, engineer, retailer, and electrical distributor) may change based on the budget and type of installation: new or retrofit. In either case, a decision web, as illustrated in Figure 2-9, shows the exchange of input among the interested parties.

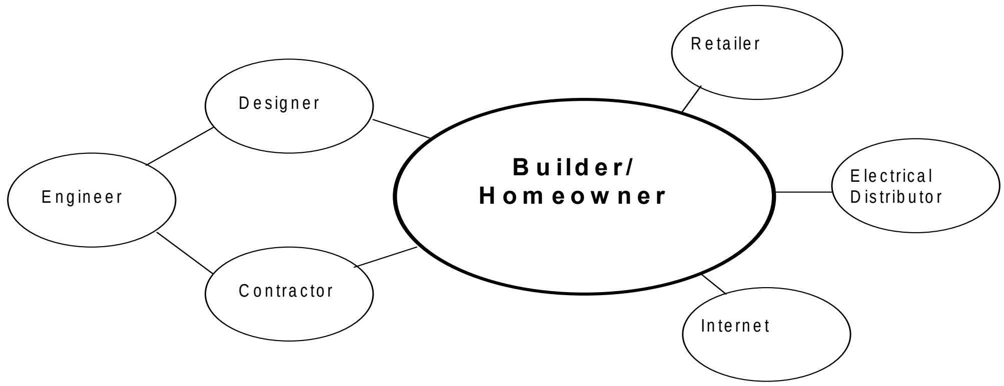

Figure 2-9: Residential Decision Web on High Intensity Discharge Lighting

For both new and retrofit installations, the builder or homeowner typically acts as the primary specifier. The budget of the development or project determines the level of involvement of the various stakeholders. The role and decision-making power of the designer and contractor typically grow with the escalating cost of the project. However, as project budgets become tighter, direct involvement with retailers, electrical distributors, and the Internet gains prominence.

2.2.3.2. Commercial, Industrial, and Outdoor Lighting Decision Makers

Conway published a study of energy-efficient lighting in commercial buildings in 1990. The original study identified key stakeholders in the decision-making process for commercial lighting. The most influential were: 1) the owner (or developer), 2) the building manager, and 3) the electrical contractor. Tying the influential decision makers into the process, Conway mapped out a decision-making web, illustrating the broad range of communication channels used. Figure 2-10 is adapted from that study, updated to represent the current HID lamp market, reflecting the author's recent review of manufacturer literature and discussions with industry experts (Conway, 2003).

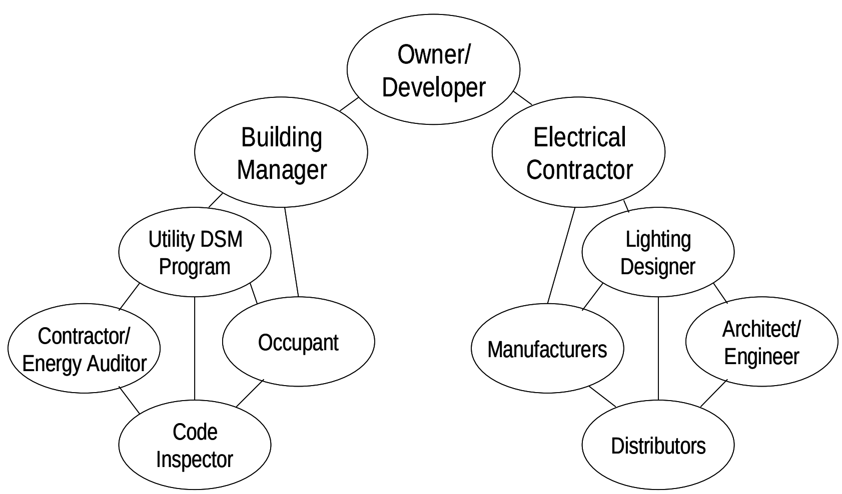

Figure 2-10: The Commercial and Industrial Lighting Design Decision Web
Source: Conway, 2003.

Some commercial businesses delegate the authority to maintain the lighting system to lighting management companies. In the public sector, local utilities, municipalities, and state highway agencies install and maintain many of these luminaires. In these two cases, the owner/developer at the top of the decision web in Figure 2-10 would include these companies or officials as the final decision makers.

2.3. Applications for High Intensity Discharge Lamps

The following sub-sections discuss where and how HID lamps are used by the residential, commercial, industrial and public sectors.

2.3.1. Residential Applications

In comparison to other lamp technologies, HID sources occupy a very small niche in the residential sector. Due to its electrical and photometric characteristics, HID lighting is not well suited for most residential applications; it is, however, used in landscape and security-lighting applications.

For security applications, MV lamps are popular because of their low initial cost and extremely long life. HPS sources, while being significantly more efficacious,[3] are more costly than comparable MV luminaires with similar light output and lamp life. Homeowners often purchase luminaires to use in their backyard at a home center or similar outlet, and typically seek lowest first cost. MH is not typically used in this application because of its shorter life, and its benefits in terms of color-rendering properties are not important for residential security lighting. In rural areas, home and farm owners may lease a security light from a utility, often a rural cooperative. This lease may carry a fixed tariff that does not measure the energy consumption. Hence, these "barnyard" lights often use MV sources.

For landscape lighting, the ability of the MV lamp to enhance the color of the foliage has created a niche application. The spectral power distribution of MV light results in greater saturation of the shorter wavelength colors (i.e., from the green to the blue). Since most of the foliage is green, the light from the MV lamp gives it a richer appearance than the lumen output of the lamp would suggest, while creating greater contrast with its surrounding objects by muting the longer-wavelength colors (i.e., red to yellow). MH lamps offer comparable performance while maintaining a much higher efficacy level; however, they have a higher initial cost and shorter operating life than MV. A review of manufacturer literature and discussion with landscape lighting designers, distributors and manufacturer representatives indicate that the primary MV lamp used for this application is the 175-watt mogul base lamp.

2.3.2. Commercial Applications

HID lamps account for about a tenth of the total lighting energy consumed for the commercial sector, with incandescent lamps accounting for about one-third and fluorescent

[3] Efficacy is the measure of energy efficiency for lamps, reporting light output (lumens) per unit of energy input (watts); thus, its units are lumens per watt.

lamps consuming between one-half and two-thirds of the total energy (NCI, 2002). In spite of their potential for significant energy savings, HID lamps are not widely used in the commercial sector for several reasons. The primary reason is a low CRI. Other limiting factors include long warm-up and re-strike times, ballast noise, limited correlated color temperature (CCT), and color shift.

Recent improvements in MH technology incorporating pulse-start systems and ceramic arc tube variants have made the MH lamp more attractive than incandescent and fluorescent sources in certain applications. However, there are some installations (e.g., security applications) where specifiers may use a MV luminaire due to its long operating life. Additionally, some gymnasiums and government buildings may still use MV lamps, typically in 175- and 400-watt fixtures. Some exterior landscape may still use the MV lamp in the 175-watt package.

2.3.3. Industrial Applications

As in the commercial sector, lighting energy consumed across industrial sub-sectors is relatively constant (NCI, 2002). However, in terms of aggregate consumption, HID plays a much larger role in the industrial sector than in either the commercial or the residential sector. It accounts for about one-third of industrial-sector electricity use for lighting, while fluorescent lighting accounts for about two-thirds and incandescent lighting accounts for less than 5% of the total lighting-related energy consumption (NCI, 2002). HID lamps are popular in the industrial sector because there are few tasks requiring high color accuracy, and the long life of the HID sources is ideal for the sector's long operating hours.

MV luminaires in wattages of 175 and 400 watts continue to illuminate the interiors and exteriors of many old industrial buildings and warehouses. HPS sources are gaining usage in these areas. However, the strobe effect of this light source requires careful installation in facilities with certain types of machinery.

2.3.4. Public Sector Applications

HID sources dominate public sector lighting installations and represent the largest application of the HID lamp technology. Public sector installations account for roughly 8% of the total electricity consumed by all lighting in the United States, and HID sources are responsible for almost 90% of lighting-related energy use in this sector (NCI, 2002) [4]. Based on market research on lighting designers, specifiers, distributors, electrical contractors and manufacturer representatives, the Department determined the predominant MV lamp wattage to be 175 watts.

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[4] Note that this is an approximation, as the Lighting Market Characterization, Volume I: National Lighting Inventory and Energy Consumption Estimate uses the term "Outdoor Stationary" when referring to light sources situated outdoors, not attached to residential, commercial, or industrial buildings. The outdoor stationary sector is dominated by public sector lighting applications (e.g., street and highway lighting, municipal lighting, traffic signals), but it is not exclusively public sector (e.g., it includes airport and runway lights, billboard lighting).

For street and roadway lighting, HPS has been gradually replacing MV because of its lower energy costs. However, some rural utilities continue to use MV for roadway lighting, because the lamp gets increasingly dimmer at the end of its life but doesn't burn out. Hence customers do not complain to the utility, allowing the utility to leave the MV lamp burning. In contrast, HPS lamps cycle on and off as they fail. If an HPS lamp cycling on and off is not replaced, the ignitor will fail, resulting in an expensive replacement of both lamp and ignitor. Lamp companies have addressed this HPS failure mode with technology improvements in recent years. Still, some electric utilities, including many rural utilities, plan to continue their use of MV lamps unless mandated otherwise (by State or Municipal ordinances or energy efficiency standards). Often, these HID luminaires are equipped with daylight sensors that turn the luminaires on at dusk and off at dawn. A preliminary analysis estimated that rural cooperatives supply about 7% of national roadway lighting (LBNL, 2003). However, accurate data are not currently available on the percentage of MV and HPS rural roadway lighting.

MH lamps are now replacing some HPS luminaires, which had replaced MV lamps. Although MH sources are less efficacious than HPS, they offer superior "white light" and color rendition. In some area and streetlighting applications, municipalities have had their requests for MH sources turned down by the utility because the maintenance costs are too high. Pulse-start MH addresses this problem, increasing lamp life as compared to the standard MH probe-start variety, however it is still shorter than typical HPS and MV lamps. Meanwhile, lamp manufacturers are addressing HPS color issues, to try and shift this orange-colored light toward “white light.” The “white light” HPS products available today offer better CRI and CCT, but these improvements come at the cost of shorter lamp life and lower efficacy. MH and white-light HPS may be considered competitors in some applications, although typically, lighting specifiers will specify MH for any application where color is important.

2.4. Classification of High Intensity Discharge Luminaires

Luminaire classifications help describe, organize and catalog the HID lamp market for easy identification by specifiers, manufacturers and consumers. The Department reviewed the various industry classification systems, and found that they focused on particular subsets of HID lighting; no single classification system cut across a sufficient range of products to represent the universe of HID lighting. The system by the International Commission on Illumination (CIE) classifies luminaires by the proportion of upward and downward light emission; however, this system is based almost exclusively in fluorescent applications. For luminaires used outdoors, NEMA created a classification system based on circular or oval symmetric distribution of light, defined in terms of its field angle. Similarly, IESNA developed a classification system for outdoor luminaires based on the shape of the area illuminated by the luminaire. Details on these three classification systems appear in Appendix C.

In the absence of a comprehensive HID classification system, the Department developed a system that takes into account the application, construction and photometrics of HID luminaires. This proposed classification system would form the basis for product applications used in the Determination Analysis.

2.4.1. Proposed High Intensity Discharge Lamp Classification System

In the following sections, the Department categorizes luminaires by selecting their most appropriate and distinguishing feature—whether in terms of their source, mounting, construction or application. The three primary groups are indoor, outdoor and specialty applications. For the indoor applications, the Department adapted the classifications and their descriptions from luminaire manufacturers' literature and the Lighting Handbook (IESNA, 2000). For the outdoor applications, the Department adapted the product applications for outdoor luminaires from the product scope defining NEMA's luminaire section (NEMA, 2003b). Although the specialty application luminaires do not account for a large portion of the general-service HID market, the Department presents these to complete the universe of HID light sources. This classification system will constitute the product applications which the Department will use in the Determination Analysis.

2.4.1.1. Product Applications: Indoor

Table 2-10 shows a summary of the suggested classifications by indoor application. More detailed descriptions of, and commentary on, each classification follow.

Table 2-10: Classification for Indoor Applications

Classification		Description
Indoor	Accent	Luminaires providing directional lighting to emphasize a particular object or surface feature or to draw attention to a part of the field of view.
	Track	Luminaires consisting of a housing for the lamp and ballast, and a track or rail that provides power and a mounting surface for the housing.
	Portable	Self-contained luminaires that can be easily moved and positioned to provide illumination for a task.
	Downlighting	Small direct-lighting units that direct the light downward. They may be recessed or surface-mounted.
	Suspended	Luminaires that may use pendants or cable, or be suspended from a post. They may be direct, indirect, or direct/indirect combination luminaires.
	High-Bay	Luminaires providing general illumination, primarily in industrial applications, where the floor-to-ceiling height is greater than 25 feet.
	Low-Bay	Luminaires providing general illumination, primarily in industrial applications, where the floor-to-ceiling height is equal to or less than 25 feet.

Source: IESNA, 2000; Manufacturer's literature, 2003.

Accent Lighting - provides directional lighting (light that is predominantly from a preferred direction) to emphasize a particular object or surface feature, or to draw attention to a part of the field of view. The ability of the light source to approximate a point source is advantageous for this class, because a point source significantly simplifies the optical design necessary to create directional lighting with specific beam patterns. Although the small point source and high CRI of the new ceramic MH make it a competitive addition to this class, the light sources in this class are typically incandescent.

Track Lighting - a system consisting of a housing for the lamp and ballast, and a mounting rail that provides power. Mounting rails may be mounted horizontally or vertically on ceilings or walls, and may be either recessed into or extended out of the surface. Although ceramic MH has become a viable alternative light source for this class, the necessity for an additional ballast component and the high cost of the ceramic MH lamps has slowed the use of those lamps in this product application. Track lighting is typically incandescent.

Portable Lighting - any self-contained luminaires that can be easily moved and positioned to provide illumination for a task. Examples include table lamps, desk lamps, torchieres, and clamp lamps. The potential use of new, low-wattage ceramic HID sources in this class seems promising, but the high cost of these low-wattage systems has delayed their adoption in this class. The light sources in this class are typically incandescent and fluorescent.

Downlighting - luminaires that are used to provide general or ambient lighting in residential and commercial spaces. They consist of a small, direct-lighting unit that directs light downward, and can be either recessed into the ceiling, surface-mounted or suspended. The low- and mid-wattage MH lamps have made many inroads into this application. However, incandescent and fluorescent sources dominate this class.

Suspended Lighting - luminaires using pendants, a cable or a post. Their light delivery may be direct, indirect, or a combination of direct and indirect. Typically, these luminaires are ornamental, manifesting as decorative chandeliers. Incandescent sources dominate this class, but fluorescent sources have made inroads, and ceramic MH looks promising.

High-Bay Lighting - luminaires that provide general illumination, primarily in industrial applications where the floor-to-ceiling height is greater than 25 feet (e.g., in industrial warehouses). Ceiling spacing-to-mounting height ratios—derived by taking the mounting distance between two luminaires and dividing that number by the mounting height—are typically less than 1.0. Thus, high-bay lighting fixtures would be spaced closer together than their mounting height. These luminaires may be recessed, surface-mounted or pendant-mounted. Due to the typically long operating hours and low priority for color accuracy in this class, HID use is dominant. Fixtures for this class are no longer manufactured for exclusive use with MV lamps.

Low-Bay Lighting - luminaires that provide general illumination in primarily industrial applications where the floor-to-ceiling height is equal to or less than 25 feet. Spacing-to-mounting height ratios are typically greater than 1.0, meaning the distance between the fixtures is greater than their mounting height. Low-bay fixtures are similar to the high-bay fixtures, except that they are usually fitted with an additional refractor to achieve the wider light distribution in areas with restricted ceiling heights. Similar to high-bay lighting, HID use is dominant. Fixtures for this class no longer require the exclusive use of MV lamps.

2.4.1.2. Product Applications: Outdoor

Table 2-11 shows a summary table of the classifications for outdoor applications. The Department first separated the outdoor luminaires into three broad types: roadway, area, and floodlighting. Roadway luminaires are designed to provide minimal illumination of large areas such as roadways, streets, bridges, tunnels, interchanges, highways, and other transient areas frequented by vehicular traffic. The Department broke these down further into architectural, streetlighting, high-mast, and specialty luminaire-type product applications. Area lighting luminaires are non-directional lighting designed to provide minimal illumination of large areas such as parking areas, walkways, courtyards, and other transient areas used by pedestrians. The Department further divided these into four product applications: large area, small area, pathway and security. Finally, floodlighting luminaires offer directional lighting, designed for exterior applications. The Department split floodlighting luminaires into landscape and sports-lighting product applications.

Table 2-11: Classification for Outdoor Applications

<table>
<tr><th colspan="3">Classification</th><th>Description</th></tr>
<tr><td rowspan="10">Outdoor</td><td rowspan="4">Roadway</td><td>Architectural</td><td>Decorative luminaires equipped with roadway optics with a maximum mounting height of 50 feet.</td></tr>
<tr><td>Streetlighting</td><td>Luminaires equipped with roadway optics mounted on an extended arm affixed to a pole for more favorable positioning of the light source (e.g., cobra head, NEMA head).</td></tr>
<tr><td>High-Mast</td><td>Luminaires equipped with roadway optics with mounting heights exceeding 50 feet.</td></tr>
<tr><td>Specialty</td><td>Luminaires equipped with roadway optics not included in the architectural, streetlighting, or high-mast classes of luminaires.</td></tr>
<tr><td rowspan="4">Area Lighting</td><td>Large Area</td><td>Luminaires designed to illuminate large areas with wattages of 250 watts or more, mounted less than 50 feet above base.</td></tr>
<tr><td>Small Area</td><td>Luminaires designed to illuminate small areas with wattages less than 250 watts.</td></tr>
<tr><td>Pathway</td><td>Luminaires used for localized illumination of walkways, grounds, and other pedestrian areas.</td></tr>
<tr><td>Security</td><td>Luminaires designed to help visually secure an area such as an entry point to a building.</td></tr>
<tr><td rowspan="2">Floodlighting</td><td>Landscape</td><td>Luminaires designed to illuminate objects of interest such as signs, building exteriors and foliage.</td></tr>
<tr><td>Sports</td><td>Luminaires equipped with precise optics and specialized mounting gear for specific light distribution patterns and glare control.</td></tr>
</table>

Roadway: Architectural - ornamental luminaires equipped with roadway optics for illuminating the road surface. They are architecturally pleasing in design and mounted up to 50 feet above a base. Light sources for these luminaires include HID, fluorescent and incandescent.

Roadway: Streetlighting - a luminaire affixed to a light or telephone pole with roadway optics for illuminating the road surface. The most common configuration for this product application is available in what industry refers to as a "cobra head" luminaire. These are typically equipped with an arm-mount that extends the light source, enabling a more favorable distribution of light on the road surface. HID sources, typically HPS and MH, are used almost exclusively in streetlighting applications, but there are some luminaires that may be manufactured with a MV lamp (e.g., "NEMA-head" and "tear-drop" luminaires). The NEMA-head luminaire is typically equipped with a 175-watt mogul based MV lamp. The tear-drop luminaire is typically equipped with a 100-watt mogul based MV lamp. Rural utilities and municipalities may still opt for MV luminaires like the NEMA head and tear-drop, due to their low initial cost and the ability of the MV lamp to continue operating for extreme lengths of time without catastrophic failure (i.e., when the lamp no longer emits light).

Roadway: High-Mast - a luminaire with roadway optics for illuminating the road surface and a mounting height equal to or greater than 50 feet. Due to the extreme mounting heights, light sources for these luminaires tend to be exclusively MH or HPS, and tend to be higher wattages.

Roadway: Specialty – this category includes other luminaires primarily used for illuminating the road surface not mentioned in the architectural, streetlighting or high-mast luminaire categories.

Area Lighting: Large Area Luminaires - luminaires with wattages of 250 watts or more mounted less than 50 feet above a base. Typical configurations include arm-mounts, post-tops and building mounts. These luminaires tend to be almost exclusively HID. Though fixtures are no longer manufactured for exclusive use with MV lamps, older installations still use these lamps.

Area Lighting: Small Area Luminaires - fixtures with wattages less than 250 watts. Typical configurations include arm-mounts, post-tops, building-mounts and other surface-mounted luminaires. Applications for these luminaires include sign lighting and billboard lighting. Municipalities and state transportation departments usually own sign lighting, and MV lamps are often used, as well as fluorescent lamps. Billboard lighting is generally privately owned and tends to use MH for its superior color rendering.

Area Lighting: Pathway Luminaires – fixtures that provide localized illumination of walkways, grounds and other pedestrian areas. Bollards are typically mounted in the ground and have the form of a short thick post. Low-mount floods are typically mounted on a wall in the immediate vicinity of the pathway of interest. Predominant sources are incandescent and fluorescent. Low wattage MV use is limited and most luminaires use MH or HPS.

Area Lighting: Security Luminaires – luminaires designed to help visually secure an area such as an entry point to a building. A wall pack or other surface-mounted luminaire may be used to create the necessary vertical illuminance for recognition of potential intruders. A lantern shape with an integrated photosensor is another common security lighting configuration found primarily in the residential sector. Commonly referred to as "barnyard" fixtures, these luminaires typically incorporate 100 watt and 175 watt MV lamps.

Floodlighting: Landscape Luminaires - used to illuminate objects of interest such as building facades and foliage. In-grade fixtures are also used for this application, with a high design factor (associated with very high initial cost). HID lamps are well suited for this application due to their high power, efficacy and long life, in addition to the optical control provided by their small point source. Due to their spectral distribution light emission, MV light sources provide good saturation of the color of plants. MH sources induce a similar saturation of color. Other common light sources for this application are incandescent and fluorescent reflector lamps.

Floodlighting: Sports Arena Luminaires – these luminaires have precise optics and are equipped with specialized mounting gear to acquire the critical distribution and glare control necessary for illuminating large open fields. MH is the most common technology used because of its good color rendering. HPS is not usually used because of the strobe effect on moving objects as well as the poor color rendition for TV cameras. Although there are no new installations of MV luminaires for this application, it is still used in some old installations.

2.4.1.3. Product Applications: Specialty

HID luminaires in specialty applications often employ lamp shapes and bases that are not typically associated with general service HID lamps discussed in the indoor and outdoor application groupings. Therefore, most lamps used in specialty applications would be exempt from standards. Although the impact from this product application would be very small, the Department has included them in this draft framework for completeness. Table 2-12 presents the three types of specialty product applications.

Table 2-12: Classification for Specialty Applications

Classification		Description
Specialty	Theatrical Luminaires	Luminaires designed with precise optical control and maximum flexibility. These are niche products used in the stage, studio and other related fields.
	Adverse Location Luminaires	Luminaires designed with special housing, gaskets, lenses, and wiring to protect against internal and external factors. Applications include harsh environments such as underwater applications and volatile industrial environments.
	Other Custom Luminaires	Luminaires that do not conform to any standard type. They typically have very specific light distributions and/or atypical form factors.

2.4.2. Mercury Vapor Lamp Product Applications

The preceding sections outlined a classification system that cuts across all HID lamp applications. This section identifies the HID product applications where the Department believes MV lamps are in use today, because they are the ones where a standard level that would result in a phase out of MV lamps would have the most impact.

After reviewing manufacturer's literature and NEMA data (NEMA, 2003a) and speaking to lighting experts and HID lamp specifiers, the Department identified critical product applications and wattages. Table 2-13 lists these MV lamp product applications by lamp wattage. A small "x" marks the wattages and applications where MV is used. A large bolded "**X**" marks the wattages where MV lamps represent a majority in a given product application.

Table 2-13: Product Applications and Wattages for the Mercury Vapor Lamp

Product Application			≤100W Med	100W Mog	175W Mog	250W Mog	400W Mog	1000W Mog
Indoor		High-Bay			x	x	**X**	x
		Low-Bay			**X**	x	x	x
Outdoor	Roadway	Architectural	x	x	**X**	x	x	
		Streetlighting		**X**	**X**	x	x	x
	Area Lighting	Large Area				x	**X**	x
		Small Area		x	**X**			
		Security	x	x	**X**	x	x	
	Floodlighting	Landscape	x	x	**X**	x	x	x

Note: A small "x" indicates wattages where MV lamps are used in a particular product application; large bold "X" indicates wattages where MV shipments are most significant.

The Department welcomes comments on the product applications and identification of lamp wattages presented in Table 2-13.

2.5. Regulatory and Non-Regulatory Programs Impacting High Intensity Discharge Lamps

As part of the Determination Analysis, the Department reviews all voluntary and compulsory programs that relate to HID lighting. This review provides the Department with a greater understanding of the marketplace in which HID lamp, ballast and luminaire manufacturers operate, as well as what programs and trends may influence the future of the market.

2.5.1. Regulatory Programs Impacting High Intensity Discharge Lamps

The Energy Policy Act of 1992 requires states to adopt an energy code for buildings, which includes energy consumption guidelines for lighting.[5] On July 15th, 2002, the Department issued a Determination that ASHRAE Standard 90.1-1999 was more stringent than 90.1-1989 (DOE, 2002a). As a result, each state must certify that it has reviewed and updated the

[5] "(b) Certification of commercial building energy code updates: (1) Not later than 2 years after October 24, 1992, each State shall certify to the Secretary that it has reviewed and updated the provisions of its commercial building code regarding energy efficiency. Such certification shall include a demonstration that such State's code provisions meet or exceed the requirements of ASHRAE Standard 90.1-1989." 42 USC 6833.

provisions of its commercial building code regarding energy efficiency to meet or exceed Standard 90.1-1999 by July 15, 2004 for any "building" under the means of Section 303(2) of the Energy Conservation and Production Act as amended. The ASHRAE/IESNA 90.1-1999 code requires that all exterior building grounds luminaires that operate at greater than 100 watts contain lamps having a minimum efficacy of 60 lumens-per-watt (LPW), unless the luminaire is controlled by a motion sensor or qualifies for one of the exceptions (ASHRAE, 1999). So far, many States have adopted ASHRAE/IESNA 90.1 as their standard for lighting commercial buildings. However a few States have developed and adopted their own building energy codes that are more stringent, such as California's Title 24. These energy codes contain provisions for interior lighting that specify performance criteria, such as lighting power density (wattage per square foot of area illuminated). For exterior lighting, the energy codes, including the proposed exterior lighting update to ASHRAE/IESNA 90.1-1999 and the proposed update to California Title 24, use a variety of metrics, including minimum efficacy (lumens/watt), watts/linear foot, and lighting power density.

Several states and a number of municipalities have passed "dark-sky" ordinances aimed at reducing light pollution. While most focus on eliminating light pollution by addressing luminaire type, some ordinances (e.g., the state of Arizona) have banned MV light sources (IDA, 2003). However, regulatory authority is not consistent; some ordinances cover only the lighting owned by the regulatory entity (e.g., State or Municipal), while others cover privately owned lighting as well. The lighting industry has attempted to work with the International Dark Sky Association to draft a model ordinance to address this issue from the best technical perspective.

In addition to these dark-sky ordinances, the Department is aware of procurement specifications, implemented on a state and municipal basis (e.g., City of Philadelphia, State of New York), which call for streetlighting fixtures other than MV. This procurement specification is not a regulatory ban on MV, but it directs these large purchasers of outdoor stationary HID lighting to move toward alternative technologies, such as HPS and MH.

2.5.2. Non-regulatory Programs Impacting High Intensity Discharge Lamps

The Department's review of non-regulatory programs promoting more efficient HID sources found that there are generally three types of programs. The first type promotes energy efficiency through sponsoring retrofits, either on a prescriptive (technology) basis or on a minimum efficacy (lumens per watt threshold) basis. The second type encourages the installation of the most efficient technology in new installations. The third type encourages more efficient technology, but with the objective of reducing peak load demand. This type of program focuses on indoor HID luminaires, rather than outdoor lighting that typically operates during off-peak hours.

In Appendix D, the Department provides a summary of several non-regulatory programs. These results are representative (not exhaustive), and demonstrate the efforts of the Department to identify and understand what programs exist throughout the nation. The summaries include a brief description of each program, the target technology, the incentives offered, and contact information for the sponsoring agency. Table 2-14 provides a list of those programs summarized in Appendix D.

Table 2-14: Non-regulatory Programs Relating to High Intensity Discharge Lamps

Program Name	Managing Organization	State
Commercial Power Saver 2003	Modesto Irrigation Department	California
Commercial and Industrial Retrofit Program	Sacramento Municipal Utility District	California
Express Efficiency Lighting Program	Pacific Gas and Electric, San Diego Gas and Electric and Southern California Edison	California
Commercial Lighting Efficiency Offer	Los Angeles Department of Water and Power	California
Express Rebate Program	Northeast Utilities	Connecticut
Energy Blueprint Program	United Illuminating	Connecticut
Commercial / Industrial Lighting Program	Florida Power and Light	Florida
Design 2000 Plus Program; New Equipment and Construction Program	Massachusetts Electric, Nantucket Electric and Granite State Electric	Massachusetts
Construction and Retrofit Program	Nstar	Massachusetts
Granite State Electric Retrofit Program	Granite State Electric	New Hampshire
Smart Equipment Choices Program	New York State Energy Research and Development Authority	New York
Commercial Construction Program	Long Island Power Authority	New York
Building Efficiency Program	Energy Trust of Oregon	Oregon
Commercial Energy Opportunities	Efficiency Vermont	Vermont
Energy Smart Services Financial Incentives	Seattle City Light	Washington

2.6. Potential Small Business Impacts

The Department will consider whether there may be an impact on small businesses if the Department were to promulgate a standard for HID lamps. If such impacts could occur, the Department will analyze those impacts a later date.

The Department requests comments on the possibility of small business impacts from HID energy conservation standards.

3. Technology Assessment

HID lamps produce light by generating an electrical discharge between tungsten electrodes contained within an arc tube. Because the electrical discharge exhibits a negative resistance, a ballast regulates this electrical discharge and prevents it from drawing excessive current that would lead to its destruction. Therefore, with one notable exception, HID lamps always operate with a ballast. The exception is a self-ballasted mercury vapor lamp. Section 3.2discusses this lamp, along with the ballasted mercury vapor lamp.

The following discussion examines and summarizes current specifications, standards and guidelines governing the classification, testing and evaluation of HID lamps.

3.1. Specifications, Test Standards, and Procedures

The Department conducted a search to review available data dealing with the evaluation of the electrical and photometric properties of HID lamps and ballasts. Table 3-1 shows a complete list of standards publications pertaining to HID lighting.

Table 3-1: Standards Documents Pertaining to High Intensity Discharge Lighting

Source	#	Year	Title
ANSI	C78.1340	1995R	450W Self-Ballasted Mercury Lamps
	C78.1341	1995R	750-Watt, 120-Volt Self-Ballasted Mercury Lamps
	C78.1342	1995R	160-Watt, 120-Volt B87 Self-Ballasted Mercury Halide Lamps
	C78.1372	1996	70-Watt, M98 Single-Ended Metal Halide Lamps
	C78.1374	1996	50-Watt, M110 Single-Ended Metal-Halide Lamps
	C78.1375	1996	400-Watt, M59 Single-Ended Metal Halide Lamps
	C78.1376	1996	1000-Watt, M47 Single-Ended Metal Halide Lamps
	C78.1377	1996	175-Watt, M57 Single-Ended Metal Halide Lamps
	C78.1378	1996	1500-Watt, M48 Single-Ended Metal Halide Lamps
	C78.1379	1996	250W, 120V, S55 Self-Ballasted Mercury Lamps
	C78.1380	1988	Electric Lamps--250 Watt, 120 Volt, Self-Ballasted Mercury Lamps Specifications
	C78.1381	1998	Electric Lamps--250 Watt, 70 Watt, M85 Metal Halide Lamps
	C78.1382	1996	100-Watt, M90 Single-Ended Metal Halide Lamps
	C78.1384	1997	150-Watt, M102 Single-Ended Metal-Halide Lamps
	C78.1385	1998	For Electric Lamps: 150-Watt, M81 Double-Ended Metal-Halide Lamps
	C78.1386	1998	For Electric Lamps: 100-Watt, M91 Double-Ended Metal-Halide Lamps
	C78.1387	2001	250-Watt, M80 Double-Ended Metal Halide Lamps
	C78.380	1997	High-Intensity Discharge Lamps, Method of Designation
	C78.386	1989	Mercury Lamps--Method of Measuring Characteristics
	C78.387	2002	Electric Lamps Metal Halide Method of Measuring Characteristics - Supplement
	C78.388	1990	High-Pressure Sodium Lamps--Methods of Measuring Characteristics
	C78.40	1992	Specifications for Mercury Lamps
	C78.42	2001	High Pressure Sodium Lamps
	C82.4	2002	Ballasts for HID and LPS Lamps (Multiple-Supply Type)
	C82.5	1995R	Reference Ballasts for HID and Low-Pressure Sodium Lamps
	C82.6	1996R	Ballasts for High Intensity Discharge Lamps--Method of Measurement
	C82.9	1996	HID and LPS Lamps, Ballasts and Transformers--Definitions
IESNA	LM-35-02	2002	Photometric Testing of Floodlights Using HID or Incandescent Filament Lamps
	LM-46-98	1998	Photometric Testing of Indoor Luminaires Using HID or Incandescent Lamps
	LM-47-01	2001	Life Testing of High Intensity Discharge (HID) Lamps
	LM-51-00	2000	Electrical and Photometric Measurements of HID Lamps
	LM-61-96	1996	Identifying Operating Factors for Installed Outdoor HID
CIE	84-1989	1989	Measurement of Luminous Flux

Source: NEMA, 2003b. IESNA website, 2003. CIE website, 2003.

NEMA, as the Secretariat for ANSI, publishes test standards for lamps (C78), bulbs (C79), lamp bases and holders (C81), and ballasts (C82) as part of its lighting standards program (NEMA, 2003b). The standards in C79 and C81 are of limited use for the purposes of this document and are omitted in Table 3-1. The C79 documents deal with incandescent lamps and generic lamp shapes. The C81 documents deal with the construction and form of the coupling from lamp to lamp holder. Discrete test procedures exist for each lamp type: ANSI C78.386 for

MV, ANSI C78.387 for MH, and ANSI C78.388 for HPS. These publications describe the procedures for measuring the electrical characteristics for each HID lamp type.

NEMA also publishes a system of nomenclature for the designation of HID lamps in their C78 technical support documents. The designation code, at a minimum, includes the class, electrical characteristics, and physical characteristics of the lamp. In addition, NEMA publishes a set of corresponding performance specifications. The designations and specifications not only provide a system of identification, but also ensure a level of product commonality and interchangeability among the manufacturers of HID lamps and ballasts.

Other organizations promulgating test standards for HID lamps include IESNA and CIE. The CIE publication deals with the quantification and measurement of luminous flux. The IESNA LM-51-00 describes the procedure for the electrical and photometric measurement of HID lamps. By definition, HID lamps include MV, MH and HPS lamps. This publication builds on the NEMA/ANSI standards (ANSI C78.386, ANSI C78.387 and ANSI C78.388) to include procedures for taking photometric measurements in addition to electrical measurements. Publications by the IESNA reflect consensus of industry stakeholders, including NEMA members. Currently, publications by these organizations exclude the evaluation of ballasts in their procedures, and contain only an electrical and photometric evaluation of the lamp itself.

IESNA LM-51-00 is the industry standard test procedure for determining the electrical and photometric performance of HID lamps. As such, this procedure defines testing conditions, lamp stabilization, and other critical aspects to ensure consistency in the testing of lamp performance and efficacy.

3.2. Mercury Vapor

Mercury Vapor (MV) was the first HID light source, introduced in the 1930's and has remained fundamentally unchanged. HID light sources are based on the principle of an arc discharge tube that produces light. In the movement toward developing more efficient lighting, one development was the invention of a self-ballasted mercury (B) lamp. This lamp originated as a direct replacement for the Edison incandescent lamp. By using a length of tungsten filament within the lamp structure to provide current regulation, the lamp is able to function without an external ballast.

Due to its low CRI, MV lamps are used primarily in spaces that are not frequently occupied by people. A phosphor coating is added to get better CRI, but the improvement is marginal. Outdoor security, streetlighting, and landscape lighting are some of the applications for MV lamps, but better-performing MH and HPS lamps are gradually replacing these. There are some niche applications where the long life and low initial cost of the MV system has allowed it to maintain market share. However, even in those niche applications, MV is losing ground as other HID sources slowly close the technology gap in life and initial cost. The MV lamps are available in wattages from 50 to 1000 watts. The most common wattage is the 175-watt lamp, followed by the 400-watt lamp, and then the 100-watt lamp (see Table 2-6).

The B lamp has carved out a special niche because of its unique ability to replace the standard incandescent lamp without a ballast. Although it offers no significant advantage in terms of energy savings, it does offer a huge advantage over the incandescent lamps in terms of lifetime, resulting in much longer intervals between relamping. B lamps are available in wattages of 160, 250, 450, and 750 watts. B lamps are facing increasing competition from other light sources, such as the integrally ballasted, screw-based, compact fluorescent lamp (CFL) that can also directly replace incandescent lamps.

3.2.1. Construction

In MV lamps, an electric current arc passing through mercury vapor in the arc tube generates light. MV lamp electrodes are usually made of tungsten. The emission material, composed of several metallic oxides, is embedded within the turns of a tungsten coil, protected by an outer tungsten coil. Energy received from the arc heats the electrodes to the proper electron-emissive temperature. Since mercury has a low vapor pressure at room temperature, and an even lower vapor pressure when it is cold, a small amount of more-readily-ionized argon gas facilitates starting. The initial arc is struck through the ionization of the argon gas. Once the arc strikes, its heat begins to vaporize the mercury, and this process continues until all of the mercury is evaporated. The amount of mercury in the lamp essentially determines the final operating pressure, which is 200 to 400 kPa (29 to 58 pounds per square inch) in the majority of lamps (IESNA, 2000).

An outer glass bulb contains the arc tube to protect the arc tube and internal electrical connections from the environment. The inner envelope (arc tube) is made of fused silica with thin molybdenum ribbons sealed into the ends as current conductors. The essential construction detail is shown in Figure 3-1, typical of lamps with fused silica (quartz) inner arc tubes within an outer envelope (IESNA, 2000).

The outer envelope (bulb) is usually in the shape of an ellipse and made of hard (borosilicate) glass, but it also can be made of other glasses for special transmission, or where pollution and thermal shock are not problems (IESNA, 2000). The outer bulb also absorbs the majority of ultra-violet (UV) energy radiated by the arc tube, while allowing light to pass through. The outer glass bulb can be coated with a diffusing material to reduce the source brightness of the lamp. This diffusing coating is usually a color-correcting phosphor that uses UV energy radiated by the arc tube to improve the lamp's overall color-rendering properties, as in a fluorescent lamp. The shape of the bulb is also available in a reflector package.

Within the outer bulb, there are wires suitable for high temperatures to conduct electricity to the arc tube and structural components to support the arc tube. The atmosphere in the outer bulb might be a low-pressure gas (usually nitrogen) or, in many cases, a vacuum (IESNA, 2000). If the outer bulb is broken and the arc tube continues to operate, the lamp will emit a significant amount of UV energy. Self-extinguishing lamps usually contain a tungsten filament, in place of a portion of nickel wire, which will oxidize quickly and separate. This separation turns the lamp off and renders the lamp inoperable.

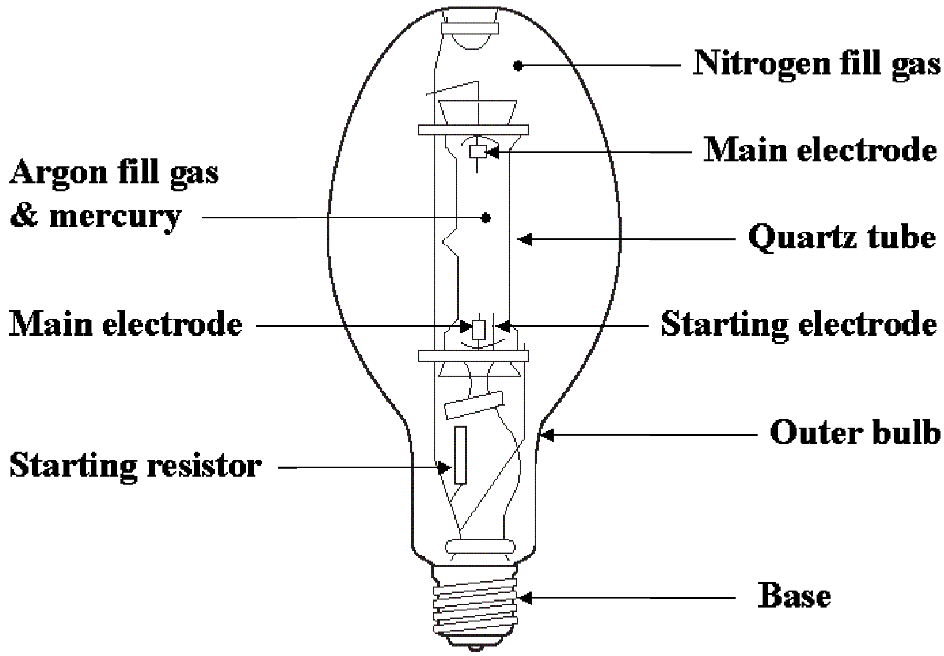

Figure 3-1: Mercury Vapor Lamp Construction.

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The self-ballasted MV lamp (B) has a tungsten filament coil inside the outer envelope that both provides ballasting and acts as a supplemental light source. The coupling for the general service MV lamp, and all other HID lamps, is typically a medium (Med) screw base or a mogul (Mog) screw base made from brass, nickel, or special alloys to minimize corrosion. Figure 3-2 shows typical HID bases with their ANSI designations.

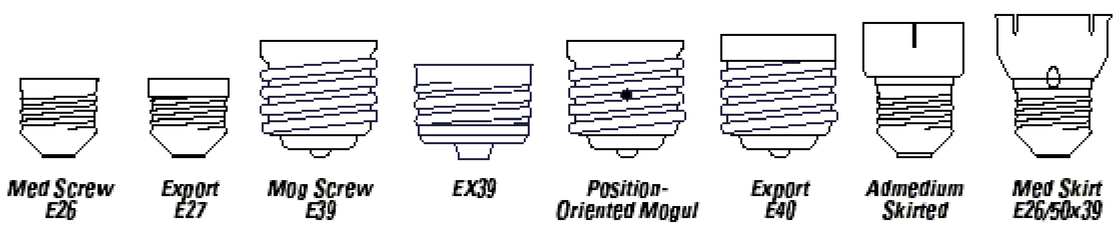

Figure 3-2: Typical High Intensity Discharge Bases with Standard Designations

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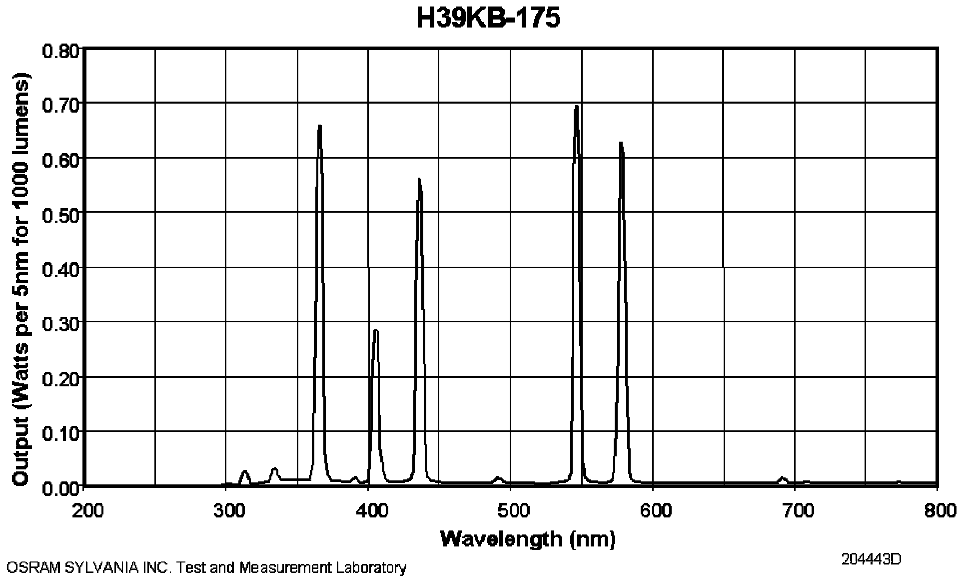
3.2.2. Lamp Performance

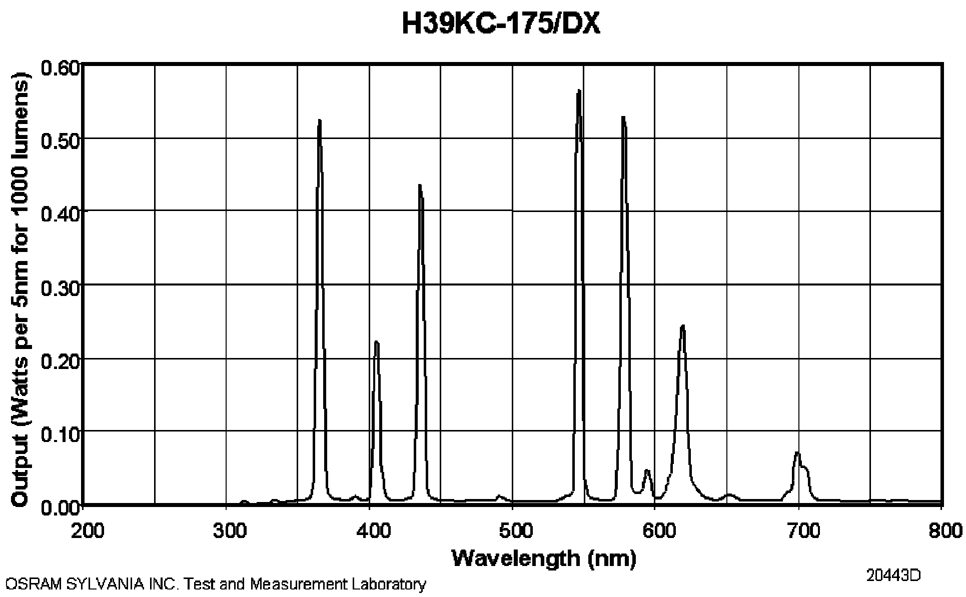
The pressure at which a mercury lamp operates has a significant impact on its characteristic spectral power distribution. In general, higher operating pressure tends to shift a larger proportion of emitted radiation into longer wavelengths. At extremely high pressure, there is also a tendency to spread the line spectrum into wider bands. Within the visible region, the mercury spectrum consists of five principal lines (404.7, 435.8, 546.1, 577, and 579 nm), which result in greenish-blue light at efficacies of 30 to 65 LPW, excluding ballast losses (IESNA, 2000). While the light source itself appears to be bluish-white, there is a deficiency of long-wavelength radiation, and most objects appear to have distorted colors. Blue, green, and yellow are emphasized; orange and red appear brownish.

The efficacies of the B lamp are slightly better than those of the incandescent lamp it replaces. Typically, efficacies range between 15 to 25 LPW. The spectrum consists of the line spectrum of the MV, in addition to the blackbody radiation pattern from the incandescent component of the tungsten filament. CCT ranges from 3300 to 4000K, with a CRI of 50, depending on the mercury pressure and the application of a phosphor coating.

Clear MV lamps generally have a CRI value of approximately 15, and are not desirable for use where people will occupy the space. Since a significant portion of the energy from the arc discharge is in the UV region, phosphor coatings on the inside surface of the outer envelope convert some of this UV radiation to visible light, as occurs with a fluorescent lamp. The most widely used lamps of this type have a coating of vanadate phosphor (designation DX) that emits long-wavelength radiation (orange-red) (IESNA, 2000). This phosphor also is blended with others to produce a cooler or warmer CCT, given in degrees Kelvin (K) from 3200K to 6700K. The phosphor coating can raise the CRI rating to 50. Figure 3-3 shows the spectral power distributions (SPDs) of a clear lamp and lamps using these phosphors.



(a)



(b)

Figure 3-3: Spectral Power Distribution of Mercury Vapor Lamps (a) Without Phosphors and (b) With Phosphors

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The light output from a MV lamp decreases over the operating life of the lamp. Typically, industry has found that light (lumen) output depreciates about 25% from its initial output level at 50% of its rated life. Its rated life is 24,000 hours, but it is not uncommon for the lamp to continue burning long after its rated life. The MV lamp has a reputation of being virtually indestructible, continuing to operate while the light output gradually decreases over time. However, as the light output declines, the power consumption remains constant – meaning that the efficacy of the light source steadily decreases with use. For the B lamp, a more modest

12,000 to 16,000 hours of rated life is reported, with slightly better lumen depreciation of 15%–20% at 40% of rated life.

To achieve the necessary high vapor pressures within the arc tube, the MV lamp requires a significant warm-up time of approximately 5 to 7 minutes. Re-strike times are about as long, requiring 5 to 7 minutes for the vapor pressure to come down to a level where the arc can be restarted. Warm-up time for the B lamp is approximately 3 minutes, with a re-strike time of 5 minutes.

Table 3-2 summarizes the performance of MV sources.

Table 3-2: Performance Summary of Mercury Vapor Lamps

Lamp Power (watts)	CRI	CCT (K)	Initial Efficacy @ 100 hours (LPW)	Mean Efficacy @ 40% life (LPW)
Less than 100	25 – 50	3200 – 5700	31 – 40	25 – 32
100	15 – 50	3700 – 7000	40 – 45	30 – 36
175	15 – 50	3700 – 6800	44 – 51	23 – 43
250	15 – 50	3700 – 6700	43 – 55	38 – 44
400	15 – 50	3700 – 6500	47 – 60	40 – 48
1000	15 – 50	3700 – 6300	55 – 64	44 – 51

3.2.3. Electrical Characteristics

Because MV lamps have an additional electrode located at one end of the arc tube to assist in lamp starting, they do not require a separate starter circuit. These lamps typically require an open circuit voltage (OCV) of approximately twice the operational lamp voltage to initiate and sustain the arc discharge.

MV lamps may operate with any of the commonly available HID ballasts, without an ignitor. MV lamps may use a reactor ballast, a high-reactance autotransformer (HX) ballast, a constant wattage autotransformer (CWA) ballast, or a constant wattage isolated transformer (CW) ballast. Taking ballast losses into account may reduce system efficacy of MV lamps (and other HID sources) 5 to 15%. That brings the efficacy range for MV systems down to approximately 26–55 LPW.

The B lamp does not require a ballast for operation. This hybrid-type lamp produces light by two mechanisms. Primarily, an electrical discharge is created across a discontinuity in the filament. Concurrently, the tungsten filament is heated to incandescence as current flows through it. Since tungsten exhibits a positive response (resistance increases) to current, current regulation is achieved as the filament counteracts the negative resistance response of the arc discharge.

3.2.4. Other Issues

Although the Occupational Safety and Health Administration (OSHA) does not require them to do so, all three lamp major manufacturers (GE, Philips, and Sylvania) provide material and safety data sheets (MSDS) for manufactured articles such as HID lamps. The MSDS reports that MV lamps contain anywhere from 15 mg of mercury in their 50-watt lamps up to 250 mg in the 1000-watt units. Although other toxic materials (e.g., scandium iodide) are in the lamps, these are present in trace amounts and are not hazards. Lead is used in soldering the connection in the lamp.

A Toxicity Characteristic Leaching Procedure (TCLP) for lead and mercury, as prescribed by NEMA standards publication LL 3-1999, resulted in MV lamps being classified as a hazardous waste. They come under the Universal Waste Rule published by the Environmental Protection Agency (EPA) on July 6, 1999. The lead in the lamp and the mercury in the arc tube pose little risk under normal use, but disposal regulations will depend on state and local requirements.

3.3. High-Pressure Sodium

Introduced in the 1960's, HPS lamps went on sale just before MH lamps. HPS is currently the most efficacious HID light source; however, its physical, electrical and photometric characteristics differ from other HID lamps, making it suitable for some applications but not others.

HPS lamps are used in applications where energy efficiency and long life are of primary concern with little regard to color rendering. Although HPS lamps are available in wattages from 35 watts up to 1000 watts, typical wattages for these applications range from 50 to 400 watts. The long and slender arc tube makes reflector design difficult. In addition, the limited color temperatures and low color rendering results in the lamp's inherent lack of variety in available product packages. Applications include outdoor stationary, commercial and industrial sectors. Commonly used as street and parking lights, HPS lamps also provide visibility and a sense of security by illuminating public access areas, subways, parks and other pedestrian areas. Large commercial and industrial buildings may use this technology where CRI and CCT are of little concern. Many of these areas of application overlap with MH; the two technologies therefore compete for market share.

3.3.1. Construction

Figure 3-4 shows the basic construction of the HPS lamps. Similar to the MH lamps, they have a two-bulb construction. The arc tube is made of a ceramic material that contains the electrodes, sodium and mercury amalgam, and a small amount of xenon. No starter probe is present in the HPS arc tube. The tube is long and slender and is made of polycrystalline aluminum oxide ceramic. The high temperatures needed to vaporize sodium dictate the geometry and material. Furthermore, the highly corrosive nature of sodium, especially at elevated temperatures, precludes the use of certain materials such as quartz, which is used in the other HID lamps. Therefore, the arc tube is manufactured from a ceramic material. An amalgam reservoir inside the arc tube helps to stabilize the pressure, similar to amalgam-based fluorescent lamps. This allows the HPS lamp to operate in any physical orientation, simplifying stocking and installation (Sylvania, 2003b).

The outer envelope is elliptical in shape and is made of a hard glass that primarily acts to protect the arc tube from damage. Usually, it contains a vacuum, which acts to reduce convection and heat losses from the arc tube to maintain high efficacy (Sylvania, 2003b).

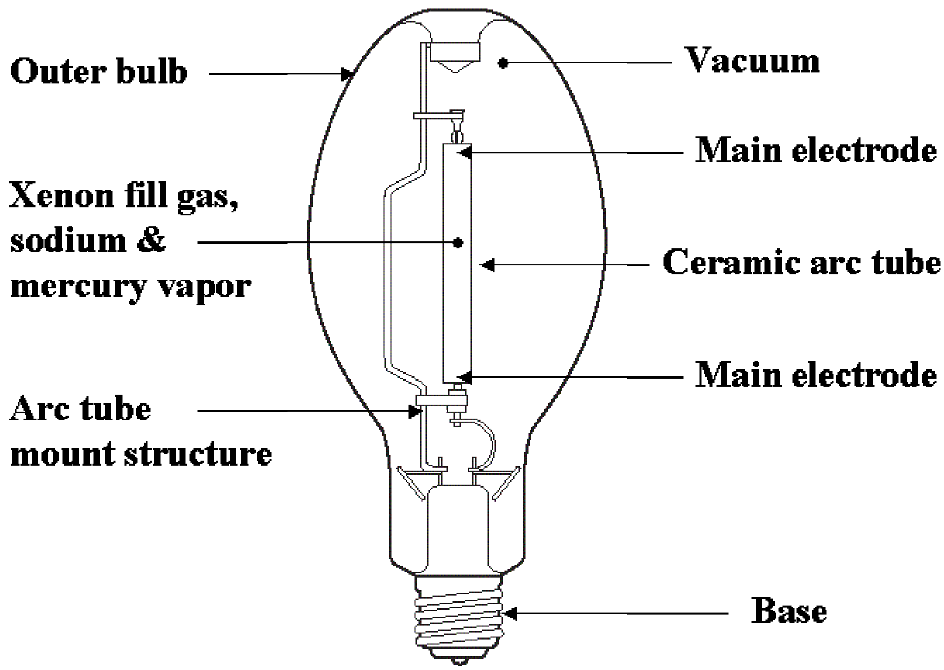

Figure 3-4: High-Pressure Sodium Lamp Construction

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In some HPS lamps, an additional coil is wrapped around the outside of the ceramic arc tube to assist in starting the lamp (Sylvania, 2003b). It is similar in function to the starting probe in probe-start MH and MV lamps. This type of HPS lamp can directly replace the MV lamps and will operate under the same ballast without an ignitor.

3.3.2. Lamp Performance

The efficiency of the HPS lamp is critically dependent on the specific vapor pressure of the sodium in the arc tube. Any deviation from this target pressure level will result in reduced performance of the lamp. However, HPS lamps offer the highest efficacy of HID sources, achieving a 64 LPW for the 35-watt source up to 133 LPW for the 1000-watt source. HPS lamps over 100-watts offer efficacies over 100 LPW. Life ratings of 24,000 hours are typical, with some long-life lamps rated at 40,000 hours. A lamp operating at 40% of its rated life has an expected maximum lumen depreciation value of 15%.

During the warm-up, the light output will go through a sequence of color shifts from red to blue to the characteristic monochromatic yellow of the sodium vapor. Ultimately, it will settle on the yellow-white of the HPS lamp (IESNA, 2000). Typical CCT values are 2000K at a CRI of 20. Higher CCT values are possible, but some trade-offs need to be made. The highest CCT commercially available is 2200K at a CRI of 70. That is achieved at the cost of reduced lifetime. Figure 3-5 shows a spectral power distribution for an HPS lamp. Application of the diffuse coating does not significantly change the spectral power distribution (SPD) of a HPS lamp.

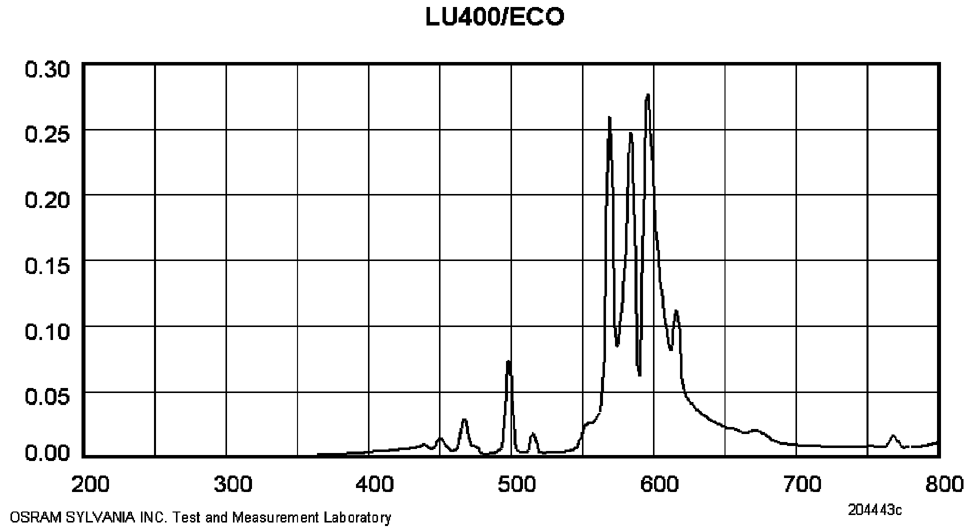

Figure 3-5: Spectral Power Distribution of High-Pressure Sodium Lamps (same distribution for bare and coated lamps)

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Table 3-3 summarizes the performance of general-purpose HPS sources.

Table 3-3: Performance Summary of General-Purpose High-Pressure Sodium Lamps

Lamp Power (watts)	CRI	CCT (K)	Initial Efficacy @ 100 hours (LPW)	Mean Efficacy @ 40% life (LPW)
Less than 100	22	2100	61 – 91	55 – 81
100	22	2100	88 – 105	79 – 94
150	22	2100	100 – 107	90 – 96
250	22	2100	104 – 120	93 – 108
400	22	2100	115 – 135	100 – 113
1000	22	2100	125 – 145	112 – 126

Table 3-4 summarizes the performance of high CRI HPS sources.

Table 3-4: Performance Summary of High Color Rendering High-Pressure Sodium Lamps

Lamp Power (watts)	CRI	CCT (K)	Initial Efficacy @ 100 hours (LPW)	Mean Efficacy @ 40% life (LPW)
Less than 100	60 – 85	2200 – 2700	47– 54	40 – 43
100	85	2700	49	42
150	60 – 65	2200	70 – 73	61 – 66
250	65	2200	90	83
400	65 – 70	2200	94	84

3.3.3. Electrical Characteristics

Due to the long and narrow arc tube geometry, the presence of xenon gas, and the lack of starting probes, an ignitor generates the high voltage pulse necessary to start the lamp. Once the arc is generated, a cold lamp will require approximately 3 to 4 minutes of warm-up time to attain full light output with a re-strike time typically ranging from 1 to 3 minutes.

Unlike the typical MV or MH lamp, whose voltage remains relatively constant throughout its lifetime, the arc tube voltage increases significantly during the operational life of the HPS lamp. Over the lifetime of the lamp, some of the sodium is lost, and as the ratio of sodium to mercury changes, the arc voltage rises. Therefore, the HPS ballast must change the operating voltage to maintain an acceptable median wattage over its lifetime. Figure 3-6 illustrates the trapezoid-shaped boundary (ANSI C78.42) that restricts the performance of the lamp and ballast to certain acceptable limits.

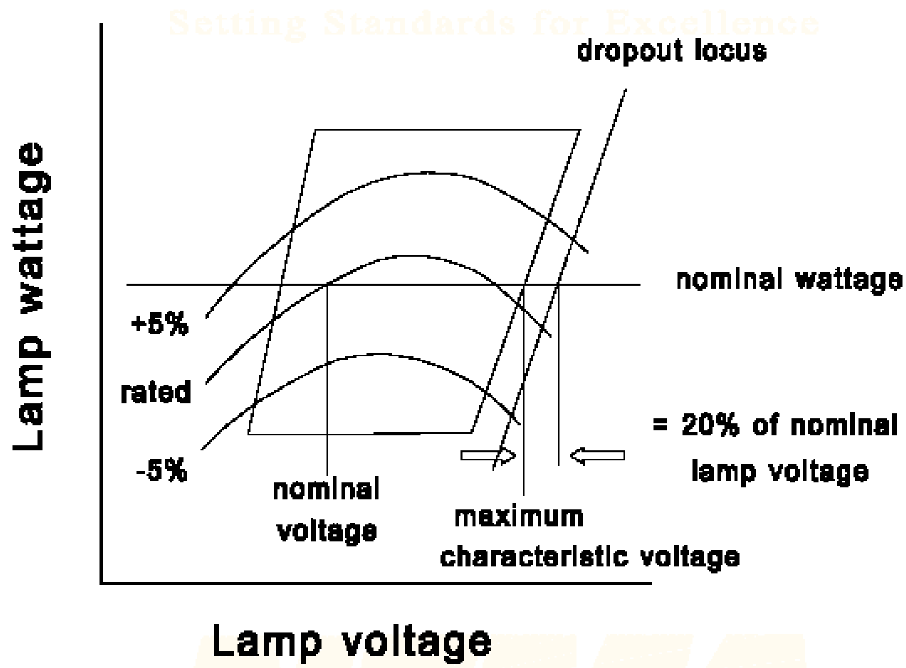

Figure 3-6: Trapezoid Boundary for High-Pressure Sodium Ballast Design

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The HPS ballast must operate the HPS lamp within this trapezoid for any input voltage within the rated input voltage-range of the ballast. Toward the end of the lamp's life, the lamp operating voltage will rise to a level beyond the ballast's ability to sustain the arc. At this point, the lamp will start, warm up to full brightness, and extinguish. The repeating of this sequence is known as cycling, and signals the end-of-life for the HPS lamp. If the lamp is not replaced within a reasonable amount of time at this juncture, premature failure of the ballast can occur.

The simplest and most economical ballast for HPS is the reactor ballast. This ballast is commonly used with 35- to 150-watt HPS lamps. HX ballasts are also used where the input voltage does not meet the starting voltage requirements of the lamp. CWA is the most popular ballast type, for reasons of balancing cost and performance (similar to MH and MV). CW ballasts are better than the previous three, but they come at a cost of increased ballast size, losses and price. These ballasts incorporate three coils in their design instead of the usual two or one; the third coil and capacitor stabilizes the lamp.

3.3.4. Other Issues

The standard HPS lamp contains small amounts of mercury used as an amalgam for the sodium. It also uses lead solder for connections. Therefore, TCLP tests classify the HPS lamps as hazardous waste, subject to state and local disposal regulations. In response, manufacturers developed mercury-free alternatives that use a non-mercury amalgam. Additionally, manufacturers developed lead-free alternatives to address other disposal concerns.

The two primary strengths of the HPS light source are its high efficacy and its long life. The poor color rendering of the typical HPS lamp limits its share of the HID market. Development of better arc tube material would be required for these lamps to attain the higher vapor pressures to increase CCT and CRI, and this would have to be accomplished while maintaining its advantage in efficacy and life. Also, development of instant restart lamps is critical to expand its marketability into fluorescent technology-dominated applications.

3.4. Metal Halide

Developed in the 1960s just after the HPS lamp, MH lamps offer the best combination of quality, performance and flexibility in the current HID lamp group. They are available in low (less than 175 watts), medium (from 175 to 400 watts) and high (greater than 400 watts) wattages.

The standard MH lamp is similar to its mercury lamp ancestors, with the major difference that the metal halide arc tube contains various metal halides in addition to the mercury and argon. When the lamp attains full operating temperature, the metal halides in the arc tube are partially vaporized. As the halide vapors approach the high-temperature central core of the discharge, they are dissociated into the halogen and the metals, with the metals radiating their light spectrum. As the halogen and metal atoms move near the cooler arc tube wall by diffusion and convection, they recombine, and the cycle repeats (Sylvania, 2003a).

The use of metal halides inside the arc tube presents two advantages. First, metal halides are more volatile at arc tube operating temperatures than pure metals. This allows the introduction of metals with desirable emission properties into the arc at normal arc tube temperatures. Second, those metals that react chemically with the arc tube can be used in the form of a halide, which does not readily react with fused silica.

3.4.1. Application

Refinements in pulse-start technology are improving MH lamp performance in almost every aspect. Average operating life of pulse-start MH lamps is now approaching the operating life of HPS and MV lamps. With MH lamp efficacy levels approaching those of HPS lamps, MH lamps can now compete with HPS lamps in outdoor applications such as roadway and parking lights, security lights, and pedestrian walkways. Furthermore, the color rendering of MH lamps are almost on par with incandescent sources through advancements in ceramic arc tube design.

The unique SPD of MH lamps may offer another advantage over HPS lamps. As light levels decrease, the spectral response of the human eye shifts to what is called the “scotopic visibility function.” The result is, under very low light “scotopic” conditions, the perceived light from a MH source may be many times greater than the perceived light from an HPS source that provides equivalent visibility under photopic (high light level) conditions[6]. This advantage may be realized in outdoor lighting installations where specified light levels are very low.

The small physical dimensions and high intensity of the arc make it an ideal point source around which to create application specific light distributions through precise optical design of a reflector. High-wattage (above 1000 watts) MH lamps appear in stadiums, in searchlights, and any other application that require powerful white light. MH lamps in low-wattage (below 175 watts) configurations illuminate a variety of applications, including billboard displays, recessed lighting, and track lighting. Very low-wattage MH lamps (in the range of 30-60 watts) appear in applications like automotive headlights and some residential lamp fixtures.

In some cases, probe-start MH lamps can directly replace MV lamps. Manufacturers produce interchangeable similar-wattage MH lamps that operate on the MV ballast. However, the MH lamp will produce significantly more light for the same wattage than the MV lamp. For example, replacing a 400-watt MV lamp with a 380-watt MH retrofit lamp achieves a power savings of 20 watts. However, the MH retrofit lamp will generate on the order of two to three times more light than the MV lamp.

3.4.2. Construction

MH lamp construction is similar to that of a MV lamp (Figure 3-7). One significant design characteristic is that the arc tubes of MH lamps usually are smaller for equivalent wattages. The arc tube is typically made of either quartz or ceramic, and contains a starting gas (usually argon), a mercury base, and a discrete mixture of metal halide salts for the desired spectral emissions. MH arc tubes operate at higher temperature and pressure than their MV counterparts. A white coating at the ends of the arc tube increases the temperature and vaporization of the metal halides by trapping the thermal energy inside the arc tube. Use of ceramic materials in the arc tube construction yields even higher temperatures and pressures, resulting in improved efficacy, CRI and color stability.

An elliptical-shaped soft or hard glass outer bulb contains the arc tube, usually made of borosilicate glass, to protect and buffer the arc tube and internal electrical connections from the environment. The outer envelope contains a low-pressure inert gas (e.g., nitrogen), or a vacuum, which helps minimize oxidation of the internal components, provide additional thermal buffering for a more stable arc temperature, and absorb some of the UV energy radiated by the arc. However, the glass itself absorbs the majority of the UV energy (Sylvania, 2003a).

The manufacturers may coat the outer glass bulb with a diffusing material. Usually, this is a phosphor coating that helps change the emission spectra for small improvements in CRI. However, the primary purpose of the coating is to reduce the source brightness of the lamp for glare control. The technology advantage of this lamp is its ability to emit the desired spectra without the addition of a phosphor coating like MV. Adding a diffuse coating to the lamp will reduce the efficiency and effectiveness of a luminaire with optics.

[6] The metric for light is the "lumen" and is defined by the photopic (high light level) sensitivity function of the human visual system.

Within the outer bulb are wires suitable for high temperatures to conduct electricity to the arc tube and structural components to support the arc tube. There might be other components, including resistors or diodes used to help start the arc discharge, and devices called "getters" to purify the atmosphere in the outer lamp. Most MH lamps use getters to overcome impurities that, if present in the outer jacket of a metal halide lamp in sufficient concentrations, can compromise performance. The predominant problems arise from hydrogen and carbon contamination.

In some MH lamps, a small nonmagnetic wire keeps the electrical connection to the electrode at the dome of the lamps separate from the arc tube. This prevents diffusion of sodium through the arc tube by electrolysis caused by a photoelectric effect when the current lead is near the arc tube (Sylvania, 2003a).

Like the other lamps in the HID group, MH lamps typically have screw bases (medium or mogul) made from brass, nickel, or special alloys to minimize corrosion. A characteristic of MH arc tubes is that they can take different forms and can be made from different materials.

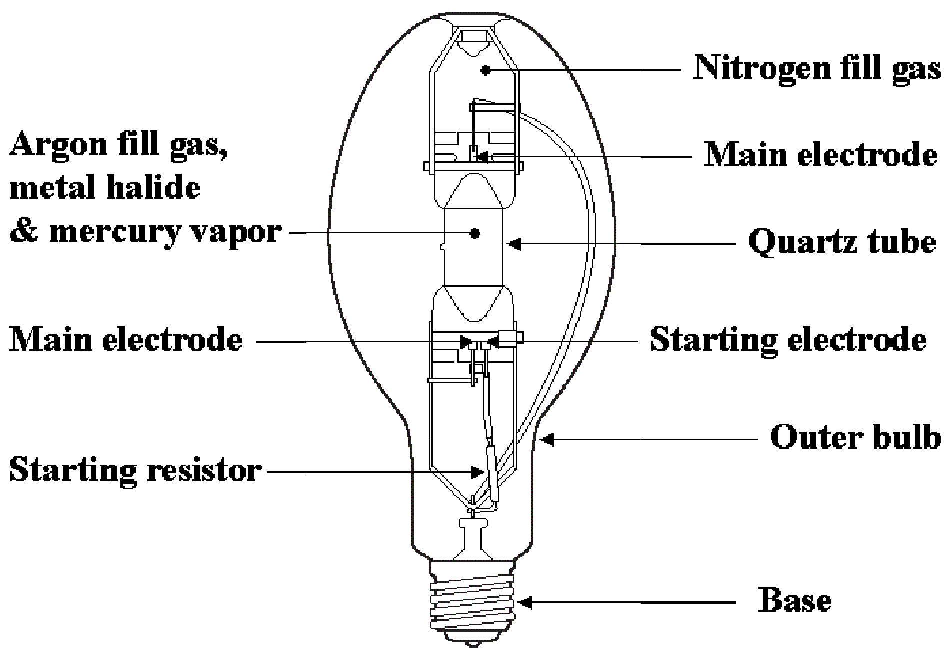

Figure 3-7: Metal Halide Lamp Construction

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In the classic, pinched-body MH lamps that use a starter electrode, the lamp body must also contain a system that provides for either shorting the starter electrode to the main electrode or opening the starter electrode circuit after the lamps have started (Figure 3-8b). This prevents electrolysis in the fused silica between the starting and operating electrodes, especially when a halide such as sodium iodide is used in the lamp. Failure to short or open the starter electrode circuit will result in very short lamp lives. These starter circuits typically use a bimetal switch. The location and type of switch can restrict the lamp operating position, as the bimetal must achieve a certain temperature to function. Lamps of this configuration are referred to as probe-start MH lamps, in reference to the presence of the starter probe in the arc tube (IESNA, 2000).

The evolution of the probe-start lamp configuration resulted not only in a different arc tube shape, but also in a new lamp design called the pulse-start metal halide (PMH) lamp (see section 3.4.3.2). In PMH lamps, the starter electrode is no longer present in the arc tube (Figure 3-8a). One of the shapes employed in the PMH lamps is the ovoid shaped arc tube. The ovoid arc tubes are actually formed in a mold using high-pressure gas. They are commonly referred to as formed-body arc tubes. However, the older-style pinched-body arc tubes, typical in probe-start lamps, are available in a pulse-start configuration (NLPIP, 2003).

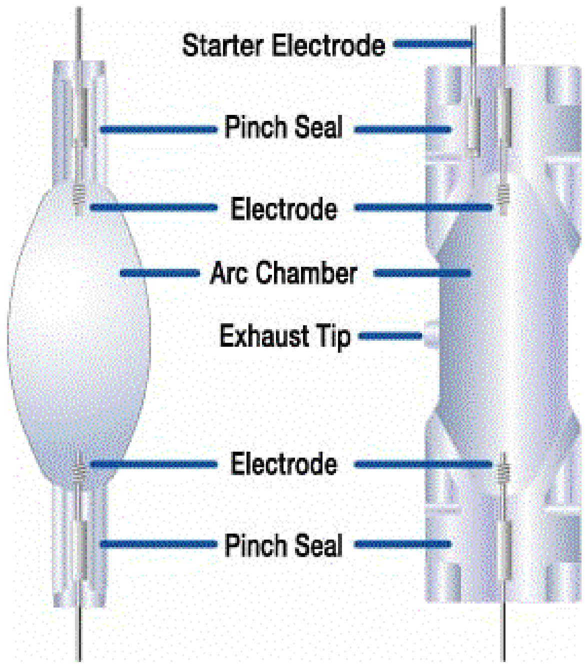

Figure 3-8: Common Arc Tubes: (a) Ovoid, (b) Pinched-Body

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The most recent iteration of the MH arc tube design incorporates the use of a new ceramic material in arc tube shape. Like the formed body arc tube, this is also a pulse-start technology, lacking a starter probe. This new arc tube material represents the newest evolution in the development of MH lamps. The lamp performance and electrical characteristics sections of this MH lamp section discuss the improvements in performance of these new shapes and materials.

To compensate for the sensitivity of the operating position for MH lamps, the arc tubes often are custom-shaped to fit the application. This is more relevant to the classic probe-start pinched-body arc tube configuration than for the pulse-start technologies. Figure 3-9 shows a typical configuration referred called a bowed arc tube shape that follows the natural bowing of the horizontal arc (Sylvania, 2003a). In this design, the chemicals are confined to the ends of the arc tube, since the shape prevents migration. Another design is an asymmetric arc tube with the electrodes lower in the arc tube body, such that the arc bows to the center of the arc tube (IESNA, 2000).

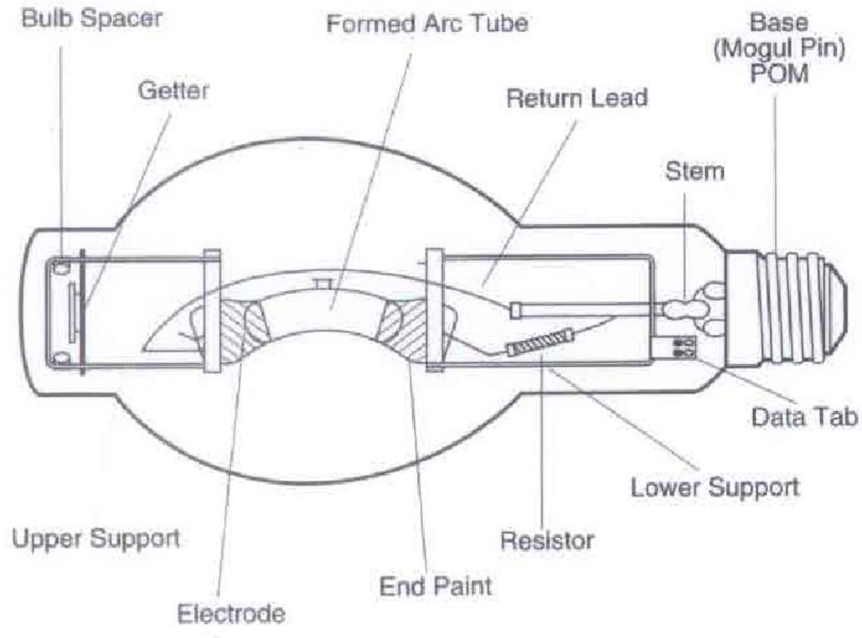

Figure 3-9: Common Configurations for Horizontal MH Lamps
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A special base and socket are always used with horizontal high-output lamps to help ensure proper arc tube orientation. In response to the sensitivity of these lamps to their operating position, a position mogul base, such as the ANSI designation EP39 Mog, is used to ensure proper positioning of the lamp for optimal operation.

Some lamps use a transparent sleeve called a shield (also known as a shroud) to surround the arc tube, illustrated in Figure 3-10. A thin-walled shroud is useful as a heat shield because it helps achieve a more uniform arc tube temperature. Lamps suitable for open luminaires use heavy shrouds. These shrouds prevent the outer jacket of the lamp from breaking in case of an arc tube violent failure. It is important to use only open luminaire-rated lamps (those with shrouds) with MH fixtures without a protective cover. Furthermore, the lack of an outer jacket will transmit UV energy. In these designs, the luminaire must have a cover glass providing the UV filtration. To prevent user misapplication, the industry has developed unique socket and base combinations for both medium and mogul base lamps.

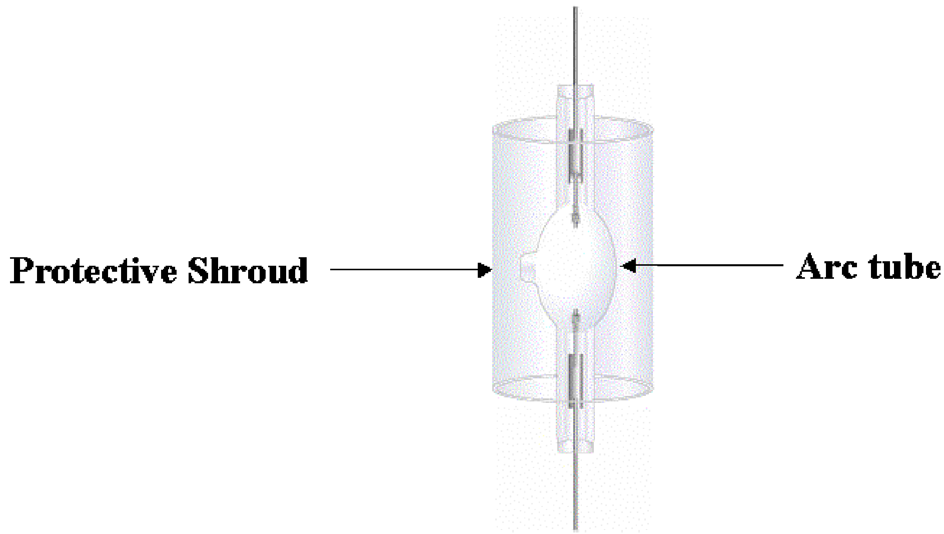

Figure 3-10: Metal Halide Arc Tube with a Shroud
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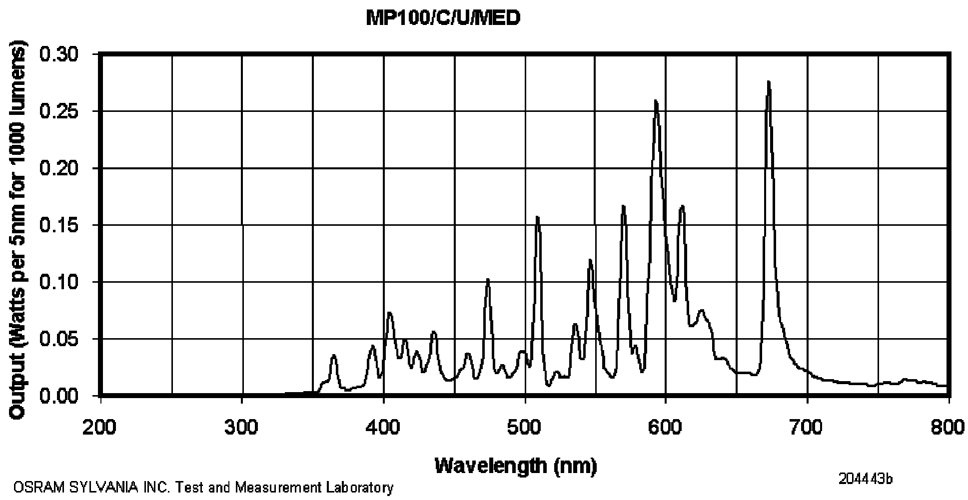
3.4.3. Lamp Performance

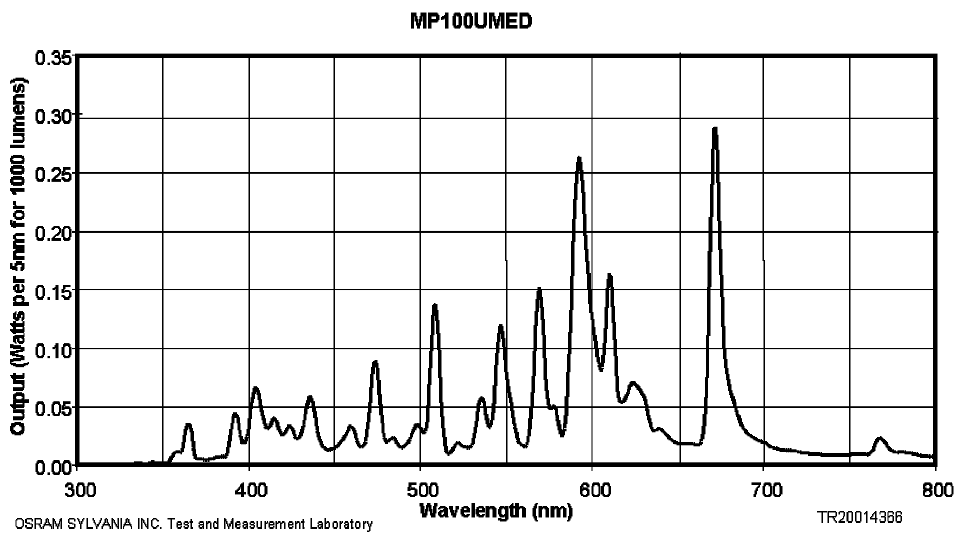
Commercially available MH lamps have efficacies of 75 to 125 LPW (excluding ballast losses), making them superior performers to MV lamps. Furthermore, almost all varieties of white-light MH lamps have color-rendering properties (approximate CRI of 70) superior to phosphor-coated MV lamps and HPS lamps. This unique capability results from their ability to tailor their spectral outputs by design.

The metal halides in these lamps have characteristic emissions that are spectrally selective. Some metals produce visible radiation at a single wavelength (i.e., sodium for orange, thallium for green, indium for blue, and iron for UV). Other metals, such as tin, when introduced as halides, radiate as molecules, providing continuous band spectra across the visible spectrum. Two typical combinations of halides used are 1) scandium and sodium iodides, and 2) dysprosium, holmium, and thulium rare-earth (RE) iodides. Various combinations of these halides can create a wide range of color temperatures for these lamps. For example, the scandium-sodium system can produce CCT values from 2500K to 5000K by varying the blend ratio and arc tube operating temperature. The rare-earth system has a characteristic CCT of approximately 5400K, which fall to 4300K with the inclusion of sodium iodide (IESNA, 2000).

Phosphor coatings can also change the spectral emission of these sources. Since phosphors convert shorter-wavelength radiation to longer-wavelength radiation, these phosphors effectively lower the CCT of the lamps by approximately 300K. Although a slight improvement in CRI may occur, the primary function of the phosphor coating is to create a more diffuse light source. These combinations of metals and their halides, and phosphors (to a lesser extent), create an almost infinite template of possibilities, giving the MH lamps a flexibility in light output design unique to the HID sources. Figure 3-11 shows typical SPD plots for MH lamps with and without a phosphor coating.



(a)



(b)

Figure 3-11: Spectral Power Distribution of Metal Halide Lamps (a) Without Phosphors and (b) With Phosphors

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A more detailed analysis of lamp performance of the probe-start MH lamp and the pulse-start MH lamp follows in the next section.

3.4.3.1. Probe-Start

The older pinch-seal designs use a secondary starter electrode that helps to initiate breakdown of the arc tube gases. However, performance of the MH lamps in this design may be affected by the physical operating orientation of the lamp. Most MH lamps are life-rated and lumen-rated in the vertical operating position. For example, a MH lamp classified as universal orientation (i.e., operates in any orientation) has its best performance in the vertical position. When a universal lamp operates horizontally, the arc bows upward due to convection currents. At the same time, the metal halide pool (which is liquid) moves to the center of the arc tube. The bowed arc moves farther from the metal halides than when the lamp is vertical, causing them to cool. This lowers the vapor pressure of the metal halide chemicals and decreases the concentration of metals in the arc, with a resulting loss in light. In addition, the bowed arc moves closer to the top of the arc tube wall, causing its temperature to increase. The higher wall loading on the arc tube material results in a decrease in life of approximately 25%.

This problem led to the development of the shaped arc tube design shown in Figure 3-9. Since the horizontal arc tubes accommodate the upward bow of a horizontally-operating arc, the lamp must operate horizontally to prevent overheating of the arc tube walls. If these lamps do not operate horizontally, users will experience a dramatic reduction in lamp life and increase the probability of a violent failure. Both of these designs provide increased light (approximately 25%) and longer life (approximately 33%) over the universal lamps with symmetrical arc tubes operated horizontally.

When operated to specifications, the probe-start lamps have a rated life from 10,000 to 20,000 hours with efficacies of approximately 90 LPW. Lumen depreciation is about 35% at 40% of rated life.

Table 3-5 summarizes the performance of probe-start MH sources.

Table 3-5: Performance Summary of Probe-Start Metal Halide Lamps

Lamp Power (watts)	CRI	CCT (K)	Initial Efficacy @ 100 hours (LPW)	Mean Efficacy @ 40% life (LPW)
Less than 100	70 – 75	2900 – 4200	60 – 69	35 – 51
100	65 – 75	2900 – 4200	77 – 90	55 – 75
175	65 – 70	3200 – 5200	58 – 85	37 – 68
250	65 – 70	3200 – 5200	76 – 92	50 – 67
400	60 – 70	3200 – 6000	81 – 105	52 – 83
1000	65 – 70	3400 – 4200	80 – 120	52 – 97

3.4.3.2. Pulse-Start

The contour and shape of a formed-body arc tube for pulse-start MH lamps give this arc tube some excellent benefits in performance. The walls of the arc tube are contoured to better follow the shape of the arc, thereby allowing for a more uniform thermal profile for the arc tube. Also, formed-body arc tubes have much smaller pinch-seal areas. This shape also allows the metal halide chemicals to heat up more rapidly than those in the conventional pinched-body arc tube. On average, formed-body arc tubes warm up three times faster than pinched-body arc tubes of the same wattage. In the classic pinched-body arc tubes, these areas served to cool the arc tube end chambers, resulting in a reduction in lamp efficacy by lowering the temperature of the metal halide pool. This undesirable cooling is more of a problem in lower-wattage lamps in which the pinch-seal area comprises a greater part of the total thermal mass of the arc tube. However, in terms of performance and light output, manufacturers claim longer life (up to 50% longer) and improved lumen maintenance (up to 33% better) than traditional probe-start MH lamps.

When operated to specifications, the pulse-start quartz formed-body lamps have a rated life from 15,000 to 30,000 hours, with a slight improvement in efficacies of approximately 100 LPW. Lumen depreciation is about 25% at 40% of rated life. In addition, burning position has virtually no effect on the performance of these lamps.

The ceramic arc tubes achieve similar results, but by different means. Their improvements are primarily a result of the advanced materials, not the shape. The material better insulates the arc tube from the environment and allows higher vapor pressures. Unfortunately, this technology is currently limited to wattages of less than 400 watts. Evolution in ceramic arc tube design will soon make higher power versions available.

When operated to specifications, the pulse-start ceramic lamps have a rated life from 9,000 to 15,000 hours, with efficacies of approximately 90 LPW. Lumen depreciation is improved to about 20% at 40% of rated life. Burning position also has virtually no effect on the performance of these lamps. The big advantage of ceramic pulse-start MH lamps over other HID sources is its ability to render color; it has a CRI value ranging from 85 to 93.

Table 3-6 summarizes the performance of pulse-start MH sources while Table 3-7 summarizes the performance of ceramic MH sources.

Table 3-6: Performance Summary of Pulse-Start Metal Halide Lamps

Lamp Power (watts)	CRI	CCT (K)	Initial Efficacy @ 100 hours (LPW)	Mean Efficacy @ 40% life (LPW)
Less than 100	70 – 75	2900 – 4200	60 – 69	35 – 51
100	65 – 75	2900 – 4200	77 – 90	55 – 75
175	65 – 75	3200 – 4000	91 – 100	64 – 80
250	65 – 70	3600 – 4000	86 – 100	66 – 80
400	65 – 70	3500 – 4000	92 – 110	58 – 88
1000	65	3800	110 – 120	86 – 96

Table 3-7: Performance Summary of Ceramic Metal Halide Lamps

Lamp Power (watts)	CRI	CCT (K)	Initial Efficacy @ 100 hours (LPW)	Mean Efficacy @ 40% life (LPW)
Less than 100	80 – 90	2900 – 4200	71 – 100	62 – 80
100	80– 93	3000 – 4200	75 – 93	64 – 75
150	80 – 96	3000 – 4200	77 – 95	58 – 81
400	90	3700 – 4000	85 – 93	72 – 79

3.4.4. Electrical Characteristics

The additional electrode located at one end of the arc tube in the probe-start lamps allows operation without requiring an ignitor circuit. A result of this configuration is that the ballasts used not only eliminate the need for ignitors, but also allow the MH lamps to share the same ballast with MV lamps, within limits. Lamp manufacturers have taken advantage of this, and produce MH lamps that operate on MV lamp ballasts. However, replacement is a more complicated issue because it raises questions about application. The Substitution Analysis Framework section (section 4) of this document addresses these issues. Probe-start MH lamps have warm-up times in the range of 2 to 15 minutes, and a re-strike time in the range of 5 to 20 minutes (Advance, 2003h).

The pulse-start MH lamp has different electrical requirements and performance results. The smaller pinch-seal area of the formed body arc tube has an effect on lamp starting. There is no room for the secondary electrode. Consequently, a high-voltage pulse (typically 3 kV minimum) applied directly across the main electrodes initiates the arc. Ignitors are used to provide these starting pulses. These lamps start faster and more reliably than their probe-start counterparts. The higher voltages generated by the ignitor allow the lamps to re-strike at much higher vapor pressures, thereby reducing the required time for the lamps to cool enough for re-ignition to take place. Furthermore, increasing the fill pressure inside the MH arc tube helps to retard tungsten evaporation from the electrode, which reduces lumen depreciation due to arc tube wall darkening. Both the warm-up time (1 to 4 minutes) and the re-strike time (2 to 8 minutes) are much shorter than those of the probe-start MH lamps, MV lamps, and HPS lamps (Advance, 2003h).

Commonly used probe-start MH ballast systems for mid-wattage MH lamps include high-reactance autotransformer (HX), constant-wattage autotransformer (CWA), constant-wattage isolated transformer (CW), and regulated lag (magnetically regulated) ballasts.

Pulse-start MH lamps require a different type of ballast than probe-start MH lamps. The ballasts used for probe-start lamps require an ignitor circuit. Commonly used pulse-start ballasts include super constant-wattage autotransformer (SCWA), reactor, and constant wattage isolated transformer (CW) ballasts. Electronic ballasts also are available for these lamps, promising even better performance.

3.4.5. Other Issues

Standard MH lamps typically contain from 5 mg of mercury, for a 35-watt lamp, up to 165 mg for a 1500-watt lamp. Lead is present in these lamps as a solder for the coupling. A TCLP test on these lamps classifies them as hazardous waste for mercury and lead. Therefore, they come under the Universal Waste Rule (EPA, July 6, 1999). State and local regulations will vary on their disposal, but recycling is recommended.

3.5. High Intensity Discharge Lamp Ballasts

HID lamp ballasts start the lamp, regulate the operating current, and provide the appropriate voltage to sustain the arc discharge. For HPS and pulse-start MH lamps, an additional ignitor circuit generates the high-voltage starting pulse necessary to initiate the arc discharge. Typical input voltages for HID lighting systems are 120V, 208V, 240V and 277V, of which 120V and 277V are the most popular. Appendix E provides summary descriptions of each ballast type from Advance Transformers: Pocket Guide to HID Lamp Ballasts (Advance, 2003a).

4. Substitution Analysis Framework

As discussed in Section 1, this analysis will assess if there are significant energy savings that are technologically feasible and economically justified for HID lamps. In order to make this determination, the Department estimates what the market response would be to such a standard. In other words, the Department makes an economic comparison between market behavior in the absence of standards (i.e., business as usual, or the base case) and the market response in the presence of standards (i.e., less-efficient lamps no longer available).

To evaluate the economic justification of a standard, the Department evaluates a base case and one or more standard levels above the base case. For this analysis, the focus is on a possible standard level at efficacies higher than those typical of today's mercury vapor HID lamps. These trial standard levels would have the effect of removing MV lamps from the HID market.

This substitution analysis framework presents substitute lighting technology options as replacements for MV lamps and fixtures. The Department considered product offerings from all NEMA lamp manufacturers in the development of this substitution analysis (see Appendix F for a complete listing of these products). This comparison will consider issues such as the cost of the affected lamps (and ballasts and fixtures, where appropriate), the energy they consume, their effective lifetime, and maintenance requirements. It will also consider technical issues, such as light output, light color, and other performance characteristics. Sections 5 and 6 of this draft framework describe the economic analyses that the Department will conduct to evaluate these trial standard levels.

Working from the complete list of applications where MV lamps are in use today (from Section 2.4.2, summarized in Table 2-13), there are three possible reasons for purchasing an HID lamp in the market today: I) to install a new HID luminaire, II) to replace a failed HID lamp in an existing installation, or III) to replace the lamp and ballast in an existing fixture (i.e., ballast failure and discarded lamp). For the purposes of this substitution analysis, the Department considers only magnetic ballasts,[7] including all luminaire components except the lamp and fixture. Thus, the ballast components include the transformer, capacitor (for power factor correction), and ignitor (for HPS and PMH). In this analysis, the Department treats the failure of any ballast component as a ballast failure. The three substitution events that would lead to the purchase of an HID lamp, ballast and/or luminaire are:

I) New Installation - The analysis compares a lighting specifier's two choices for a new installation: A new MV luminaire or a new luminaire using a different light source (e.g., MH, HPS, fluorescent).

[7] Section E.1.1 of Appendix E discusses electronic HID ballasts, noting the small market share they currently command, and the technical issues that still need resolution. The Department is not considering electronic ballasts for any of the substitutions.

II) Lamp Replacement – A MV lamp has failed, and the maintenance team needs to replace the lamp. In the absence of standards, the replacement will be another MV lamp. However, if there is a standard in place that removes MV lamps from the market, the maintenance team may respond in three ways: a direct substitution with a lamp that operates on the existing MV ballast, a lamp/ballast replacement, or a completely new luminaire. The direct substitution involves using a screw-in direct replacement HPS or MH lamp, which will operate on the existing MV ballast and within the constraints of the MV fixture optics. In the lamp/ballast replacement scenario, the maintenance team may choose to keep the same MV HID fixture, but replace the lamp and ballast to operate with a different HID light source (which complies with the new standard). Clearly, for the optics to be consistent, the lamp size of the replacement will have to be the same as the original MV lamp. Finally, the maintenance team may choose to simply install a completely new luminaire, including a new lamp, ballast and fixture.

III) Lamp and Ballast Retrofit - A MV ballast has failed and needs replacement, or a maintenance team has decided it wants to upgrade all the HID lamp fixtures at a given site. Within this scenario, there are two possible responses. The maintenance team can either retrofit a new lamp and ballast into the existing MV fixture (making sure the light output and optics of the new lamp match that of the retired MV lamp), or replace the entire luminaire.

Table 4-1 summarizes these three possible substitution event scenarios for MV lamps, ballasts, and luminaires. These three possibilities represent all the replacement scenarios the Department is considering in the event that an end-user cannot install, replace, or retrofit a MV lamp.

Table 4-1: Mercury Vapor Substitution Event Scenarios

Substitution Events	MV System Baseline	Replacement System	Description
I New Installation	Luminaire	Luminaire	Compare replacement of a MV luminaire with a compliant luminaire of equivalent light output
II Lamp Replacement	Lamp	Lamp	Compare replacement of a MV lamp with that of a compliant screw-in direct replacement lamp
	Lamp	Lamp/Ballast	Compare replacement of a MV lamp with that of a compliant lamp and ballast combination utilizing the existing fixture
	Lamp	Luminaire	Compare replacement of a MV lamp with that of a compliant luminaire (lamp, ballast, and fixture)
III Lamp/Ballast Retrofit	Lamp/Ballast	Lamp/Ballast	Compare retrofit of a MV lamp and ballast combination to a compliant lamp and ballast combination of equivalent light output
	Lamp/Ballast	Luminaire	Compare retrofit of a MV lamp and ballast combination to a compliant luminaire (lamp, ballast, and fixture) of equivalent light output

The following sections explore the three MV installation types (i.e., new installation, lamp replacement and lamp/ballast retrofit) and possible market responses, identifying replacement lamps, ballasts and luminaires.

4.1. New Installations

For new installations, the Department is basing the substitution analysis on a direct comparison between the baseline and a luminaire with equivalent light output and distribution. The fact that only two major MV luminaire types are available from the key HID luminaire manufacturers simplifies the analysis. One, the NEMA head luminaire used for streetlighting, has two possible replacements – MH or HPS. The second is a lantern shaped security-type luminaire that can be pole-mounted or wall-mounted on the exterior of buildings. This luminaire has three possible replacements: CFL, MH, and HPS. In addition to these two major luminaire types, a limited number of landscape lighting applications specify MV luminaires. Although manufacturers do not market these MV luminaires explicitly, fixtures may be custom-ordered with any HID light source, as long as the shape of the lamp and the coupling of the base are consistent with ANSI bulb and base specifications (ANSI C78.40).

4.2. Mercury Vapor Lamp Substitution Technology Options

There are three possible ways an end-user could respond to the need for replacing a failed MV lamp under a regulatory framework where MV technology is no longer available in the market: (1) install a retrofit lamp, (2) install a new lamp and ballast, or (3) replace the entire luminaire.

4.2.1. Mercury Vapor Lamp-to-Lamp Direct Substitution

The first substitution for the lamp replacement case compares the substitution of a replacement lamp for a MV lamp. The lamp is a direct replacement that can take the place of a MV lamp, matching the lamp shape and base, without any changes to the existing fixture and ballast. Table 4-2 lists all the direct replacement options available today.

Table 4-2: Direct Lamp-to-Lamp Replacement

175 MV (Mogul BT/ED28)	250 MV (Mogul BT/ED28)	400 MV (Mogul BT/ED37)	1000 MV (Mogul BT56)
150 HPS	215 HPS	325 MH 400 MH 300 HPS 360 HPS	950 MH 750 HPS 940 HPS

Note: Shaded boxes are the most common MV wattages, and represent the scenarios that the Department will consider in the LCC analysis (see Section 5) for this type of replacement.

Table 4-2 identifies the most likely replacement wattages for the MV lamps. For the 400-watt MV lamp, the 400-watt MH lamp would have much greater light output, but no realized energy savings.

The Department invites stakeholder feedback on the direct lamp-to-lamp replacements presented in Table 4-2. Are there other lamps that the Department should consider?

4.2.2. Mercury Vapor Lamp-to-Lamp/Ballast Substitution

The Department is basing the second substitution analysis for the lamp replacement case on a comparison of the cost of a MV lamp to the cost of a replacement lamp/ballast combination. This case involves replacing both the lamp and ballast in an existing MV luminaire. The bulb shape and coupling must meet the same ANSI specifications. The Department will consider only options with light output greater than or equal to the existing MV source. Light output is based on the rated mean-lumen output of the bare lamp. Table 4-3 lists the options the Department will consider for this lamp replacement case.

Table 4-3: Lamp-to-Lamp/Ballast Substitution

MV Lamp	Replacement Lamp		Corresponding Replacement Ballast		
	Technology	Wattage	ANSI Designation	Type	Voltage
100 Medium B17	PMH	70	M98	HX	120
	HPS	50	S68	HX	120
	HPS	70	S62	HX	120
	HPS	100	S54	HX	120
100 Mogul B23.5	HPS	50	S68	HX	120
	HPS	70	S62	HX	120
	HPS	100	S54	HX	120
175 Mogul B28	PMH	100	M90	HX	120
	MH	150	M57	HX	120
	HPS	150	S55	HX	120
	MH	175	M57	HX	120
	PMH	150	M102	HX	120
	PMH	175	M137	HX	120
250 Mogul B28	MH	175	M57	CWA	multi
	PMH	150	M102	CWA	multi
	HPS	150	S56	CWA	multi
	PMH	175	M137	CWA	multi
	MH	250	M58	CWA	multi
	PMH	200	M136	CWA	multi
	PMH	250	M138	CWA	multi
	HPS	250	S50	CWA	multi
400 Mogul B37	HPS	250	S50	CWA	multi
	PMH	320	M132	CWA	multi
	MH	360	M59	CWA	multi
	MH	400	M59	CWA	multi
	PMH	350	M131	CWA	multi
	PMH	400	M135	CWA	multi
	HPS	400	S51	CWA	multi
1000 Mogul BT56	MH	1000	M47	CWA	multi

Note: Shaded rows represent the most likely replacements for MV lamps, and represent the scenarios that the Department will consider in the LCC analysis (see Section 5).

The Department invites stakeholders to comment on the technologies shown and the shaded lamp/ballast combinations selected in Table 4-3. Are there other lamp/ballast combinations that the Department should consider or select?

4.2.3. Mercury Vapor Lamp-to-Luminaire Substitution

The third lamp replacement case considers the substitution of a MV lamp with a luminaire of equivalent light output and distribution. The Department identifies likely substitution technology options for these applications, based on luminaire availability and performance. For each case, the Department considers substitution technology options with light output equal to, or greater than, that of the original MV source, as shown in Table 4-4.

Table 4-4: Mercury Vapor Lamp-to-Luminaire Substitutions

Luminaire Types	100 MV Mogul E17	175 MV Mogul E28	250 MV Mogul E28	400 MV Mogul E37	1000 MV Mogul E56
High-Bay		CFL (4x26w) T-8 (3x32w) 100 PMH 70 HPS	CFL (6x32w) 175 MH 150 PMH 150 HPS	CFL (6x42w) T-5HO(4x54w) 250 MH 250 PMH 200 HPS	T-5HO(6x54w) 450 PMH 750 PMH 400 HPS
Low-Bay		CFL (4x26w) T-8 (3x32w) 100 PMH 70 HPS	CFL (6x32w) 175 MH 150 PMH 150 HPS	CFL (6x42w) T-5HO(4x54w) 250 MH 250 PMH 200 HPS	T-5HO(6x54w) 450 PMH 750 PMH 400 HPS
Roadway Architectural	70 PMH 50 HPS 55 QL	100 PMH 70 HPS QL 85	175 MH 150 PMH 150 HPS QL 165	250 MH 200 PMH 250 PMH 200 HPS	450 PMH 750 PMH 400 HPS
Streetlighting	50 HPS 70 HPS	100 PMH 70 HPS	175 MH 150 PMH 150 HPS	250 MH 250 PMH 200 HPS	450 PMH 750 PMH 400 HPS
Large Area			175 MH 150 PMH 150 HPS QL 165	250 MH 250 PMH 200 HPS	450 PMH 750 PMH 400 HPS
Small Area	42 CFL 55 QL 70 PMH 50 HPS	100 PMH 70 HPS QL 85			
Security	42 CFL 70 PMH 50 HPS	100 PMH 70 HPS	175 MH 150 PMH 150 HPS	250 MH 250 PMH 200 HPS	
Landscape	42 CFL 70 PMH 50 HPS	100 PMH 70 HPS	175 MH 150 PMH 150 HPS	250 MH 250 PMH 200 HPS	450 PMH 750 PMH 400 HPS

Note: Shaded boxes represent the most common MV wattages for each of these product applications, and represent the scenarios that the Department will consider in the LCC analysis (see Section 5).

For each of the eight product applications, shaded boxes highlight the most common MV wattage found in those applications. The Department selected these MV wattages based on feedback from NEMA and lighting specifiers, and the Lighting Market Characterization report (NCI, 2002). The Department will conduct an LCC analysis on each of the shaded boxes; however, the NES analysis will consider MV shipments across all the product applications (including the MV shipments and the substitution technology options in the non-shaded boxes).

The Department invites stakeholders to comment on the replacement luminaires shown in Table 4-4. Are there other luminaire replacements that the Department should consider or some that the Department should remove?

4.3. Lamp/Ballast Retrofit

For the scenario where both the lamp and ballast of an existing MV luminaire need replacing, the Department considers two possible outcomes: 1) replacement of the MV lamp/ballast with a substitute lamp/ballast, and 2) replacement of the MV lamp/ballast with an equivalent (performing) luminaire.

4.3.1. Mercury Vapor Lamp/Ballast-to-Lamp/Ballast

The first replacement option is to substitute an alternative lamp/ballast for a failed MV ballast and its lamp in an existing MV luminaire. The bulb shape and coupling must meet the same ANSI specifications, and the Department considers only options with a bare lamp mean light output equal to or greater than the existing MV lamp. The replacements are identical to the ones presented in Table 4-3. The difference in this scenario is that, for the baseline, The Department will include the cost of MV ballasts, along with the cost of MV lamps.

4.3.2. Mercury Vapor Lamp/Ballast-to-Luminaire

The second replacement option is to substitute a new luminaire for a failed MV ballast and its lamp. For this case, an entire luminaire replaces the MV luminaire. The Department considers only luminaires with light output greater than or equal to the existing MV luminaire. For the baseline, the Department must include the cost of the MV lamp ballast, along with the cost of the MV lamp. The replacement options take into account the lighting service that the MV luminaire had been performing, and thus will match the substitutions presented in Table 4-4.

4.4. Summary

Based on these scenarios and substitution technology options, Table 4-5 presents a summary of the LCC inputs by product application.

4.4.1. Summary of Relevant Substitution Analyses

The MV substitution analyses presented in Table 4-1 do not apply to all the product applications and wattages that the Department will consider in the Determination Analysis. For example, some of the product applications may not have any new installations of MV luminaires, rendering the new installation substitution analysis unnecessary. Therefore, based on preliminary market research on manufacturers, distributors and lighting specifiers, the Department will look at only those specific types of substitution analyses for the product applications and MV lamp wattages shown in Table 4-5. As presented in Table 4-1, the substitution analyses correspond to the following:

I. New Installation
II. Lamp Replacement
III. Lamp/Ballast Retrofit

When constructing the NES analysis (Section 6), the Department will estimate the likelihood of each of the three substitution events occurring. These estimates will be based on lamp and ballast lifetimes, estimated operating hours and an estimated growth rate for new installations.

For the LCC analysis (Section 5), within a Type II and Type III substitution event, there is more than one action an end-user may take. For example, for a Lamp Replacement (Type II), each of three replacement scenarios is possible; therefore the Department will develop a likelihood replacement weighting, such as 30% Lamp-to-Lamp, 25% Lamp-to-Lamp/Ballast and 45% Lamp-to-Luminaire. The appropriate weighting estimates will be based on the IESNA recommended practices and consultation with industry experts, including specifiers, distributors, designers and manufacturers. The Department will conduct LCC analyses on those replacement options that have significant replacement weights according to these sources.

Based on the LCC results and consultation with industry experts, the Department will also develop likely substitution technology option weights for the technologies that will replace the baseline technologies (see Section 5 for further discussion).

The Department will perform the LCC analysis on each replacement case separately. The Department will use both the replacement weighting and the substitution technology option weights in the NES, as discussed in Section 6, when combining these scenarios into an aggregate national estimate of energy savings.

Table 4-5: Summary of Proposed Substitution Event Analyses

Product Applications	100 MV Mogul E17	175 MV Mogul E28	250 MV Mogul E28	400 MV Mogul E37	1000 MV Mogul E56
High-Bay				II, III	
Low-Bay		II, III			
Roadway Architectural		II, III			
Streetlighting	II, III	I, II, III			
Large Area				II, III	
Small Area		II, III			
Security		I, II, III			
Landscape		II, III			

The Department invites stakeholders to comment on the replacement scenarios presented in Table 4-5. Are the correct types of substitutions considered for each of the product application? Are there some that the Department should drop or some that the Department should add?

4.4.2. Relevant Components for the Life-Cycle Cost and National Energy Savings

This section summarizes all the components (lamps, ballasts, and luminaires) for which the Department will need to gather price data to conduct its economic analysis. The Department's methodology for gathering these inputs appears in Section 5, Life Cycle Cost and Payback Period Analysis, and Section 6, National Energy Savings Analysis.

There are at least 25 lamps for which the Department will require average industry prices for the analysis. Table 4-6 presents these lamps.

Table 4-6: Lamp Types by Technology

MV	MH	PMH	MH Direct	HPS	HPS Direct	FL
100 Mog BT/ED23.5 175 Mog BT28/ED28 400 Mog BT37/ED37	150 Mog BT28/ED28 360 Mog BT37/ED37	70 Med* E/ED17 70 Mog* ED28 100 Med* E/ED17 100 Mog ED28 320 Mog BT37/ED37	325 Mog ED37	50 Med* ED/B17 50 Mog ED23.5 70 Med* ED/B17 70 Mog* ED23.5 150 Mog BT28/ED28 200 Mog* ED/ET18 250 Mog ED37	150 Mog BT28/ED28 300 Mog BT37 360 Mog BT37/ED37	26 watt* 4-pin CFL 42 watt* 4-pin CFL 32 watt 48"* 4-pin T-8 54 watt 48"* 4-pin T-5HO

* Lamps needed to complete luminaire package

Table 4-7 lists the ballasts for which the Department needs to obtain input data. There are 10 ballasts in total. All ballasts greater than 150 rated watts are CWA multi-tap ballasts capable of operating at a variety of input voltages (typically 120/240/277/480). The other ballasts are reactor types (HX) designed to work at a single input voltage of 120 volts. The ballast includes the coil and core, capacitor, and ignitor (for HPS and PMH).

Table 4-7: Ballast Types by Lamp Technology

MV	HPS	MH	PMH
H38-CWA-multi H39-CWA-multi H33-CWA-multi	S55-HX-120 S68-HX-120 S50-CWA-multi	M57-HX-120 M59-CWA-multi	M90-CWA-multi M132-CWA-multi

Finally, Table 4-8 lists the luminaire types for which the Department will need to obtain input data. There may be large variability in pricing, depending on the manufacturer, quantity, and product chosen.

Table 4-8: Luminaire Types by Technology

MV	MH	Pulse MH	HPS	Other
Security: 175 watt Streetlighting: 175 watt	High-Bay: 250 watt Large Area: 250 watt	High-Bay: 250 watt Low-Bay: 100 watt Roadway Architectural: 100 watt Streetlighting: 100 watt Large Area: 250 watt Small Area: 100 watt Security: 100 watt Landscape: 100 watt	High-Bay: 200 watt Low-Bay: 70 watt Roadway Architectural: 100 watt Streetlighting: 70 watt Large Area: 70 watt Small Area: 70 watt Security: 70 watt Streetlighting: 50 watt Landscape: 70 watt	High-Bay: 6x42w CFL Low-Bay: 4x26w CFL High-Bay: 4x54 T-5HO Low-Bay: 3x32 T-8 Small Area: 85 watt Induction

It is important to note that manufacturers typically package the luminaire without the lamp. In other words, they package and sell only the fixture and ballast. Therefore, the Department may need to determine the price of the associated lamp separately, and then add this to the cost of the fixture and ballast package, in order to calculate the total price of the luminaire.

5. Life-Cycle Cost and Payback Period Analysis

Increasing the energy efficiency of a product in order to comply with a standard affects the costs of purchasing and operating the product. Higher-efficiency products usually have an increased purchase price and decreased operating costs. For this reason, the Department will perform a LCC analysis to determine whether the operating cost savings (reduced electricity bills) are sufficient to justify the higher end-user installed cost of the technology that meets the possible standard compared to the installed cost of the baseline.

For the purposes of this Draft Framework for Determination Analysis of Energy Conservation Standards for HID Lamps, the Department will analyze an energy conservation standard that results in higher-efficacy HID lamps. The Department will analyze the LCC for individual installations in order to assess the net economic impacts of various substitution technology options that a standard may require.

5.1. Treatment of Sectors

The Department will calculate the LCC for each product application, for the sectors that typically use the luminaires in that product application. This section presents brief explanations of each sector of the LCC analysis. See Section 5.6, Life-Cycle Cost Cases, for details on product applications that the Department will analyze for each sector.

Commercial Sector. This sector includes luminaires used for interior lighting in commercial buildings. It also includes exterior lighting attached to, or associated with, a commercial building or complex of buildings whose owner pays for the lighting, whether it is metered along with the interior lighting or metered separately.

Industrial Sector. This sector includes luminaires used for interior lighting in industrial buildings. It also includes exterior lighting attached to, or associated with, an industrial building or complex whose owner pays for the lighting, whether it is metered along with the interior lighting or metered separately.

Public Sector. This sector accounts for those luminaires from the outdoor stationary sector described in Section 2.4.1.2 that provide public roadway lighting (including rural roadways), streetlighting, and area lighting (including parking lot lighting) not associated with the residential, commercial or industrial sectors.

Residential Sector. This sector includes residential outdoor lighting.

5.2. Life-Cycle Cost

The LCC is the sum of the total installed cost (i.e., to purchase and install a product) and the operating costs over the product life. For this analysis, the Department discounts and sums lamp and ballast replacement costs and lifetime operating costs, such as electricity costs. It then adds these costs to the total installed cost to obtain the LCC, as shown in Equation 5.1.

$$LCC = P + \sum \frac{O_t}{(1+r)^t} \qquad \text{(Equation 5.1)}$$

Where:

P = Total installed cost ($)
Σ = Sum over analysis period
O_t = Annual operating cost ($)
r = Discount rate for life cycle cost
t = Lifetime (years)

The Department calculates the LCC by adding the installed cost and all the annual operating costs until the end of the equipment lifetime. It discounts future costs to the year of initial purchase before adding them to the installed costs. The analysis calculates the LCC savings as the difference between the LCC of the baseline technology option and the LCC of the technology option after standards. If the LCC of the technology option after standards is lower, then the difference is positive and is expressed as "life cycle cost savings." Figure 5-1 illustrates the total LCC for two technology options, a baseline (no standards) and a substitution technology option (after standards).

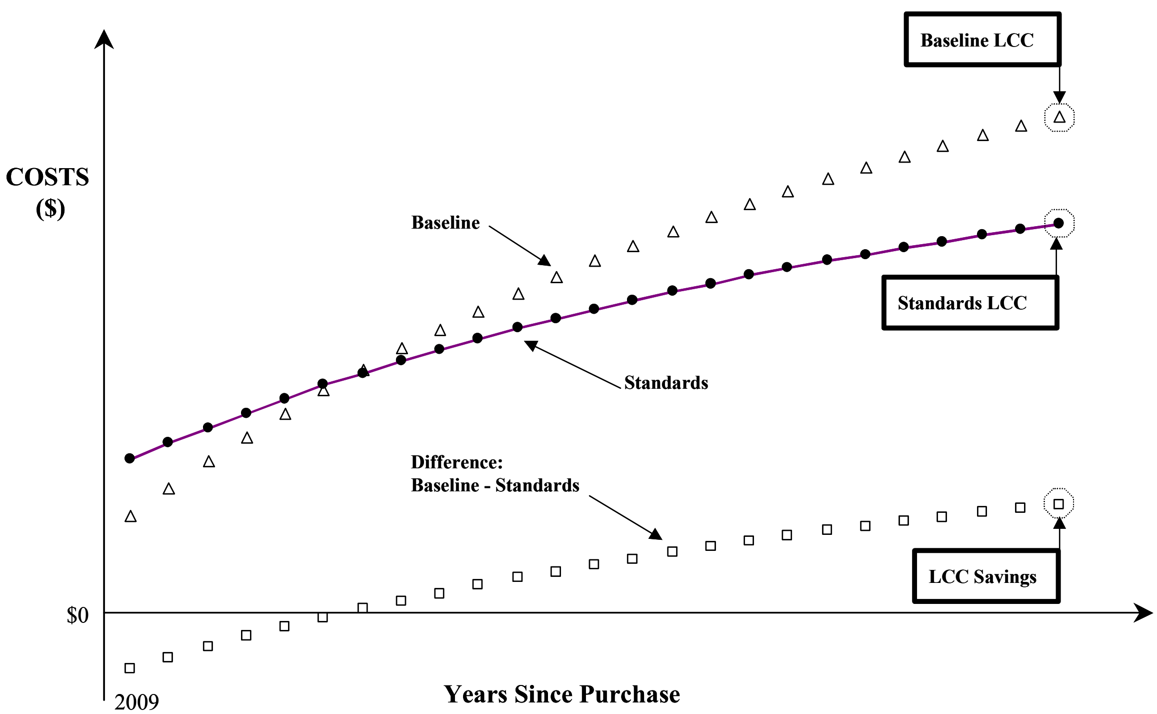


Figure 5-1: Illustration of Life-Cycle Costs for Two Technologies: Baseline and Standards

In each case, the initial purchase involves installed costs (to pay for the HID system and its installation). Typically, the more energy-efficient substitution technology option required in the standards case has a higher initial equipment cost than the baseline technology. Over the years that the HID system is in use, the system incurs lamp replacement costs and, in some cases, ballast replacement costs, as well as operating costs, including electricity costs. The baseline system uses more electricity than the more efficient substitution technology option in the standards case, so total costs accumulate more quickly over time for the baseline technology than for the standards case substitution technology option.

Figure 5-2 provides a flow diagram, illustrating the inputs, calculated values, and outputs in the LCC analysis. A representative value or a range of values (for sensitivity analysis) will represent each input. The Department will label data sources in the LCC spreadsheet and fully document them in a spreadsheet user's guide. For review and use by non-technical users, the spreadsheet incorporates pull-down menus for sensitivities (e.g., alternative assumptions).

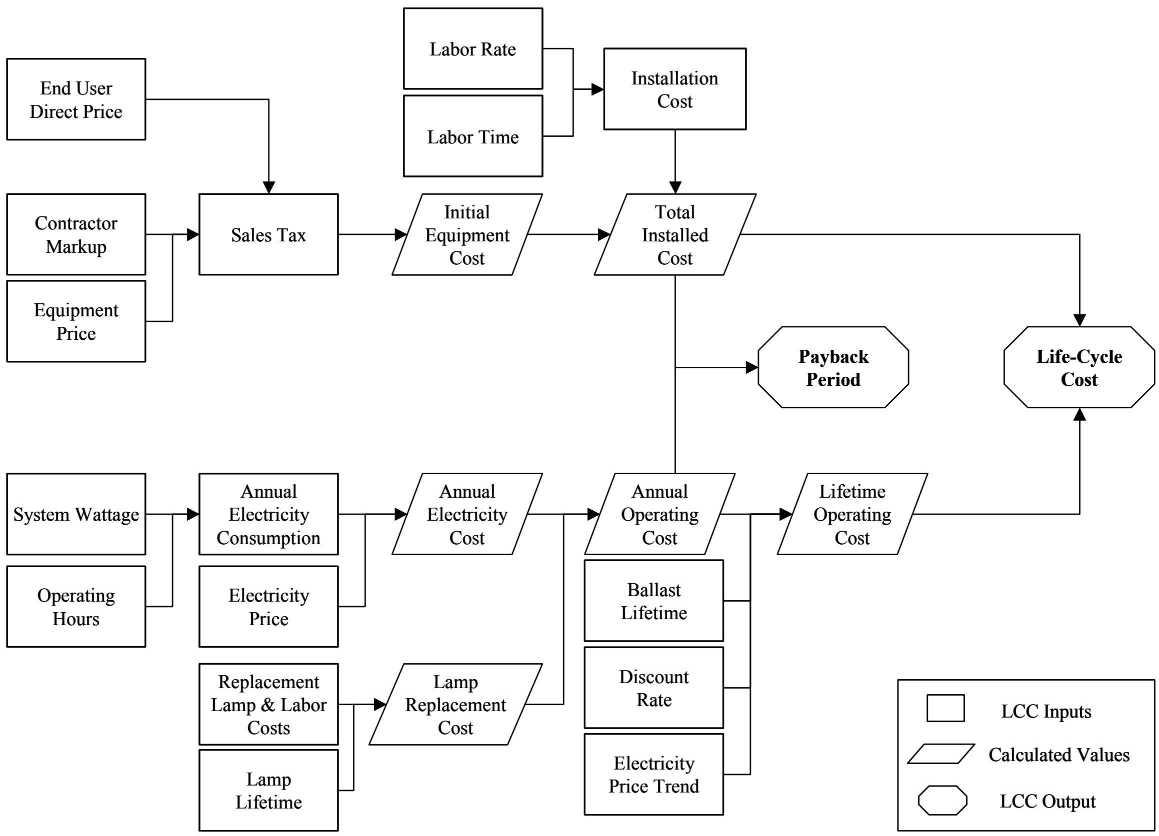


Figure 5-2: Flow Diagram of Life-Cycle Cost Analysis for High Intensity Discharge Lamps

The Department will conduct the LCC analysis using representative values to reflect product prices and lifetimes, energy costs, energy usage, and discount rates. The Department will analyze the LCC of the baseline technology (MV) and one or more substitution technology options (usually MH and HPS options). The LCC *difference* is the savings (or costs) associated with each substitution technology option relative to the baseline. The following sections discuss the LCC inputs and describe the intended approach for obtaining them. For some inputs, the Department proposes a value to use, based on previous analysis or publicly available information. For other input variables, the Department proposes method(s) of obtaining input values. When the Department has completed its research on these inputs, it will publish the intended inputs to the LCC analysis. This will provide stakeholders with an opportunity to comment on the proposed inputs and methodology. Section 5.6 below presents more detail on the LCC cases that the Department will analyze.

IESNA's Lighting Handbook, 9th edition (2000), presents a calculation method for the LCC of lamps. Appendix G of this document describes this method and compares it to the proposed calculation method. Appendix G also shows that the payback period methods described here and in the IESNA Handbook are essentially the same.

The Department requests stakeholder comments on the proposed LCC calculation method.

5.2.1. Income Tax Effects

The Department is considering whether to include the impact of income taxes in the LCC analysis for this Determination. The Department recognizes that there are two ways in which taxes affect the net impacts attributed to purchasing more energy efficient equipment compared to baseline equipment: (1) energy efficient equipment typically costs more to purchase than baseline equipment which in turn lowers net income and may lower company taxes; and (2) efficient equipment typically costs less to operate than baseline equipment which in turn increases net income and may increase company taxes. In some cases these two tax impacts balance each other out, in other cases tax benefits outweigh costs, and in still other cases tax costs outweigh benefits. In general, the Department believes the net impact of taxes on the LCC analysis depends upon: (1) firm profitability and (2) firm "expense" practices (how firms expense the purchase cost of equipment). In the case of firm profitability, data from the Internal Revenue Service (IRS) and the Value Line survey indicate that a large percentage of firms do not pay taxes.[8,9] Thus, for these firms, income taxes have no bearing on the LCC analysis. For those firms that do pay taxes, the firm's "expense" practice, such as straight-line depreciation, accelerated depreciation, and first year expensing, affects the degree in which taxes are lowered.

The Department seeks input on whether income tax effects are significant enough to warrant inclusion in the LCC analysis for the Determination. The Department specifically requests information on how many firms that purchase HID equipment actually pay taxes and, if they do, what "expense" practices are utilized to depreciate the purchase costs.

5.3. Total Installed Cost

The total installed cost for an HID system includes the equipment cost and the installation cost as shown in Figure 5-2.

[8] IRS, Statistics of Income Bulletin, Winter 2001-2002, Publication 1136 (Rev. 2-2002).
[9] Damordoran, Aswaith. New York University. Stern School of Business. Accessed June, 2003. http://pages.stern.nyu.edu/~adamodar/ (Click on *Updated Data*. Download Excel spreadsheet providing company-specific information at top of *The Data Page* by clicking on the "clicking here" button.)

5.3.1. Equipment Cost

The purchaser of the equipment pays the equipment cost, which includes the sales tax applied to the equipment price. The equipment price is either the end-user's direct price or, if the equipment is purchased through a contractor, the manufacturer's equipment price plus a contractor markup.

Because HID lamps are part of a lamp/ballast/luminaire system, the Department needs prices for all of these components. The initial equipment price includes lamp, ballast, and luminaire. When a lamp or ballast burns out, a substitution event occurs in which an end-user replaces only the lamp, or the ballast and lamp, or the entire luminaire. For each of these events, the corresponding equipment cost is considered, i.e., replacement lamp, ballast and lamp, or the entire luminaire, respectively.

There are several approaches the Department is considering to determine equipment prices. The Department will exercise some or all of the approaches, which are shown in Table 5-1. The Department recognizes that the price differs according to the number of lamps purchased (e.g., single lamp or bulk purchase of a large quantity) and proposes to arrive at an average cost for each sector. The Department expects single lamp purchases to be more common for residential applications, and bulk purchases to be more common for commercial and industrial applications.

The Department requests that stakeholders comment on these proposed methods and provide any additional sources they believe the Department should consider.

Table 5-1: Potential Sources of High Intensity Discharge Equipment Pricing

Source	Description	Method
Electrical Distributors and Electrical Contractors	Product-specific pricing information will be gathered from firms and individuals regularly engaged in the trade of selling or purchasing of lighting fixtures and lighting products.	The prices obtained will establish a 'user net' price, that is, the price a contractor or 'end user' would reasonably expect to pay for the selected luminaire, ballast, or lamp. In selected instances, published pricing available via electronic media will be used to corroborate pricing that has been provided by contacts or where direct pricing is not available or practical.
Manufacturer Blue Book Averages	Blue Book prices are the manufacturer list prices, generally representing the upper part of the pricing range. Manufacturers and distributors develop discount multipliers to apply to the list prices in order to calculate the electrical contractor's price, which the contractor then marks up for the end-user.	Contract one or more lighting specifier(s) to review Blue Book prices lists of the major manufacturers, identify the most common products specified, and calculate average Blue Book prices to use. The Department will estimate typical discount schedules provided to lighting contractors to arrive at a final selling price.
Internet Sources	www.bulbs.com www.homedepot.com Other sources	End-user pricing; bulk procurement price reductions
General Services Administration	Negotiated price schedules for all federal purchasing officers of HID light sources.	Publicly-available information; prices paid for HID lighting systems
State Purchasing Offices	Some States coordinate purchasing through one entity to secure larger procurements and better prices.	Contact State Purchasing Officers and request pricing schedules on HID lighting technology.

The Department is aware that there are a number of important issues regarding lamp equipment pricing. These include the typical discounts applied to list prices, the price variability associated with bulk procurement opportunities, and the apportionment of shipment volumes by each of the six distribution channels identified in Figure 2-8 in Section 2.2.2 of this draft framework. These issues will impact the price ultimately used as an input to the LCC.

The Department requests stakeholder comments on how to handle this variability in discount multipliers, price, and shipment apportionment by distribution channels.

5.3.1.1. Contractor Markup

For the contractor markup on HID lighting, the Department proposes using 15%. For the Department's energy efficiency standards rulemaking for fluorescent lamp ballasts (DOE, 2000), the contractor markup was 13%. HID lighting often has higher mounting heights, requires special equipment, and has higher risks for the contractor calling for a slightly higher markup rate.

The Department requests stakeholder comments on contractor markup and other sources for this information.

5.3.1.2. Sales Tax

State and local sales taxes vary in the U.S. from 0 to 10%, with a population-weighted national average of 6.7%. The Department obtained information on State sales taxes from the Federation of Tax Administrators (FTA, 2003) and information on local taxes from the Sales Tax Clearinghouse (STC, 2003). The Department derived population by state from the U.S. Census Bureau (Census, 2003b). The Department intends to use 6.7% for the sales tax.

The Department requests stakeholder comments on data sources and methods for estimating and weighting sales taxes.

5.3.2. Installation Cost

The installation cost involves both the time to install or replace a lamp, ballast, or luminaire and the associated labor rate. A new installation incurs the costs of the luminaire including the ballast, and the initial lamp. Replacements include the cost of lamp, lamp and ballast, or lamp, ballast and fixture, depending on the specific case. The Department will quantify differences in labor time (e.g., between installing a lamp and replacing a luminaire) and include these in the LCC analysis.

5.3.2.1. Labor Times

The Department proposes to use existing estimates of the amount of time required to replace a lamp, ballast and lamp, or complete luminaire, based on the 2003 Craftsman National

Electrical Estimator. For the product applications established in section 2 of this draft framework, the amount of time required to replace a lamp, replace a lamp and ballast, or install a new luminaire will vary, depending primarily on the mounting height of the luminaire.

The Department requests stakeholder comments on data sources and the proposed method for estimating labor times.

5.3.2.2. Labor Rates

The Department will estimate labor rates (dollars per hour) from R.S. Means Electrical Cost Data 2002 and from Census Bureau reports. The Department will estimate labor rates for maintenance workers responsible for lamp replacement and electrical contractors responsible for replacing ballasts and installing hard-wired fixtures.

The Department requests stakeholders to suggest other sources that the Department should review for labor rates or labor classifications associated with the installation, maintenance, and operation of HID lamps.

5.4. Lifetime Operating Cost

The lifetime operating cost includes the annual operating costs, discounted over the LCC analysis period at an appropriate discount rate, using a projection of electricity prices for the analysis period. Elements of the Department's proposed methodology for performing this LCC analysis are as follows:

- The analysis period starts in 2011, the probable start year for possible standards.
- The Department proposes to express all monetary results as 2002 dollars.
- The analysis will discount energy cost savings and equipment costs in the LCC analysis to the year that standards are assumed to start (2011).

5.4.1. Ballast and Lamp Lifetimes

For this draft framework, all the HID ballasts and luminaires considered in the substitution analysis (Section 4) are electromagnetic ballasts. The Department proposes to use 50,000 hours as the HID ballast lifetime, based on information from a major ballast manufacturer (Advance, 2003).

The service life of the HID ballast (in years) is the rated ballast lifetime (in hours) divided by its annual operating hours. Annual operating hours are specific to each product application and sector.

The LCC analysis will use manufacturers' catalogs to determine rated lamp lifetimes. For lamp replacements, the Department will estimate current relamping hours (the number of hours after which end users typically replace lamps) through consultations with experts from lighting maintenance companies. In many cases, end users "spot replace" lamps when they fail (on average, at the end of rated lifetime) and, in other cases, end users "group replace" all of the lamps in a space as preventive maintenance. Relamping hours are a weighted-average of the percentages of spot replacement and group replacement.

The Department requests comments from stakeholders on lamp and ballast lifetimes. The Department also requests comments on relamping practices for HID lamps, specifically the relative likelihood of spot replacement and group replacement.

5.4.2. Discount Rate for Life-Cycle Cost

The calculation of consumer LCC requires the use of an appropriate discount rate to calculate the present value at the time of purchase of future annual operating costs. The discount rate approximates the cost of capital for those who will make the required investment in HID lamps that will meet a possible energy efficiency standard. Conceptually, the cost of capital reflects all of the funding sources available to the owner, including debt financing and retained profits (owner's equity). Consequently, the most appropriate discount rate depends on the characteristics of the businesses, institutions, or other parties affected by a standard.

For the recent commercial fluorescent ballast rulemaking (DOE, 2000), the Department used a (real or inflation-adjusted) discount rate of 8%, with sensitivities performed at 4% and 15%. For this analysis, the Department proposes to use the same discount rates for the commercial and industrial sectors. It will base a discount rate for roadway, street, and area lighting on the national average state and local bond rate, adjusted for inflation. The proposed discount rate based on Federal Reserve Board data is 3%, with sensitivities of 1% and 7% (FRB, 2002). The rationale for this approach is that both municipalities and state highway agencies use bonds to finance capital and operating costs. The proposed discount rate for residential outdoor lighting will be 6% with sensitivities at 2% and 10%. Those are the same residential discount rates the Department used in the LCC analysis of standards for residential central air conditioners and heat pumps in 2002 (DOE, 2002b).

The Department requests comments from stakeholders on the discount rates it intends to use in the LCC Analysis.

5.4.3. Annual Operating Cost

Annual operating cost is the annual electricity cost plus any operating or maintenance costs. For HID luminaires, lamps are replaced as they burn out individually or at a predetermined time interval (typically 75% of rated lamp life) as in the case of group relamping. The Department will calculate lamp replacement costs in the year in which they occur and will add them to electricity costs to determine annual operating cost.

5.4.3.1. Annual Electricity Consumption

The Department will calculate energy consumption as the product of wattage and operating hours.

Wattage – The Department will take system (lamp/ballast) wattages from current manufacturer catalogs.

The Department requests stakeholder comments on the proposed method for obtaining wattages.

Operating Hours – The Department proposes to use operating hours for the commercial, industrial, and public sectors adapted from the Lighting Market Characterization (NCI, 2002), shown in Table 5-2. These hours are based on a national database of lighting audits of existing buildings for the commercial and industrial sector, and on data from state and local transportation agencies for the public sector. Operating hours for outdoor security and landscape applications are generally from dusk to dawn. The Department proposes to use the same hours for the residential sector as those proposed for the public sector, since both use photo sensors that turn lights on after sunset and off before sunrise.

Table 5-2: Annual Operating Hours for High Intensity Discharge Lighting

Product Application			Commercial Sector	Industrial Sector	Public Sector	Residential Sector
Indoor		High-Bay	3690	5080		
		Low-Bay	3690	5080		
Outdoor	Roadway	Architectural			4140	
		Streetlighting			4140	
	Area Lighting	Large Area	4140	4140		
		Small Area	4140	4140		
		Security	4140	4140		4140
	Floodlighting	Landscape	4140			

The Department requests stakeholder input on the operating hours for the luminaire types in Table 5-2.

5.4.3.2. Electricity Prices and Trends

The annual electricity cost is the product of electricity consumption of the HID luminaire and the annual electricity price. The price of electricity varies from one installation to another, depending on who operates it. Typical HID lighting installations include roadway lighting (operated by State and Federal transportation departments and rural utilities), streetlighting (operated by local governments), and area and outdoor security lighting (operated by local governments, and commercial, industrial and residential customers). The Department will develop an electricity price for each product application in each applicable sector.

Current electricity prices - For highway lighting, the Department will estimate average retail electricity prices from the Energy Information Administration (EIA)'s Form 861 for the year 2000 (EIA, 2000). The Department will determine the average from a price distribution to reflect the range of variation among utilities. Data for electricity sales and revenues are available by utility type, including cooperatives, municipal, investor-owned utilities, and power marketers.

Preliminary analysis of the EIA data gives an average revenues/sales for highway lighting of 9.0 – 11.0 cents/kWh. The Department proposes to use this as an estimate of streetlighting prices, subject to further analysis to determine whether this price differs significantly between publicly owned versus privately owned utilities. The Department will also research whether the Department can use this data from those cooperatives and municipal utilities that serve rural areas to estimate the price for rural roadway lighting.

For commercial and industrial lighting, the Department has estimated a marginal price of 8.8 – 9.0 cents/kWh. The Department will further investigate whether to adjust this value to account for the timing of HID usage, which may occur predominantly during nighttime hours.

The Department will also research the costs of electricity for residential outdoor lighting. Some of these lighting systems are leased from utilities, while the rest are owner-installed and connected to the residential meter. Additional information sources for rural lighting may include the National Rural Electric Cooperative Association (NRECA) and the Rural Utilities Service (RUS) of the U.S. Department of Agriculture.

Complications in estimating electricity prices will arise for several reasons. The price of electricity for streetlighting may need to account for the fact that some lighting customers may pay a flat (fixed $) based on number and type of fixtures, irrespective of the amount of electricity used. The use of a flat fee rather than a tariff impacts the relationship between customer energy and monetary savings. EIA highway lighting data also include cases where municipalities do not pay for streetlighting, and frequently lighting power is estimated rather than metered. There is also a great deal of divergence in the per-kWh rate estimate from the EIA data for small utilities, which are mostly cooperatives. For all of these reasons, the Department is considering examining a set of utility tariffs to get a more accurate estimate of marginal electricity prices, including those for smaller or rural utilities.

Electricity Price Trends - Estimating operating costs over the life of the lamps requires future electricity prices. The Department will base trends in future electricity prices on reference case projections of national average electricity prices for streetlighting and commercial, industrial, and residential customers obtained from EIA's Annual Energy Outlook 2003 (EIA, 2003). Future electricity price sensitivity cases (i.e., high and low economic cases) also will come from this source.

The Department requests stakeholder comments on sources for electricity price data for the commercial, industrial, public, and residential sectors, as well as other sources that indicate future trends for these prices.

5.4.4. Period of Analysis

The period of analysis for calculating LCC is usually based upon the service life of the technology. In the case of HID lamps, the lifetimes differ among components (lamp, ballast and luminaire) and among technology options (MV lamp vs. MH lamp vs. HPS lamp). Since some of the baseline lamp technologies have different lifetimes than the substitution technology options that will be substituted for them in the standards cases, any single period of analysis will not correspond to the service life of all the technology options. To facilitate a fair comparison of costs among different technology options with different service lives, the Department analyzes all technology options within each substitution event over the same period of analysis.

The Department proposes to use one ballast service life (see Section 5.4.1 for definition) as the period of analysis for substitution events I (new installation) and III (ballast failure) and to use half of one ballast service life as the period of analysis for substitution event II (lamp failure). The proposed period of analysis in years for events I and III is 50,000 hours divided by operating hours (by product application and sector) and the proposed period for event II is 25,000 hours divided by operating hours.

The shorter analysis period for event II (lamp failure) corresponds to half the ballast service life. As it is unknown how long any ballast in this event has been operating when the lamp fails, the Department assumes that the representative ballast in the LCC analysis has been in service an *average* of one-half a ballast lifetime.

5.4.5. Lamp Replacement Costs and Terminal Values

The Department includes the first lamp for a new installation in total installed cost. It calculates the number of subsequent lamp replacements during a ballast lifetime by dividing the ballast rated lifetime, in hours, by the lamp rated lifetime, in hours, and rounding to the next lower integer. This assumes that, when the ballast reaches the end of its operating life, its partially used lamp is discarded. In the LCC, the Department includes the cost of replacing lamps (including equipment and labor) and adds them to electricity costs for determining operating costs.

As discussed above, the analysis period for substitution events I (new installation) and III (ballast failure) corresponds to one ballast service life. For these events, the LCC calculation accounts for lamp replacement costs in the year in which they occur and discounts them to the first year.

For the standards cases of event II (lamp failure), the period of analysis does not correspond to the service life of the direct replacement lamp, the replacement ballast or replacement luminaire. Therefore, the Department intends to take account of terminal values for the equipment at the end of this shortened analysis period. A terminal value is the remaining value of the technology option from the end of the period of analysis to the end of its service life. The terminal value is applied as a "credit" at the end of the period of analysis. For example, in the analysis of direct lamp replacement in response to a lamp failure, if the period of analysis is 6 years and the lamp service life is 6 years, there is no terminal value. But if the period of analysis is 6 years and the lamp service life is 8 years, then there is value remaining in the lamp after the period of analysis corresponding to the 2 years of remaining lamp service life. The terminal value is prorated, so 2/8 of the installed cost of the lamp is applied as a credit (subtracted from the LCC) in the last year of the period of analysis, and discounted to the first year. For an event II, a terminal value of half the initial ballast costs or half the luminaire costs will be incorporated into the LCC calculation, since the analysis period encompasses only half of the ballast service life of these options.

5.5. Payback Period

Based on the same inputs, a simpler measure of the impact of an energy-efficiency standard is the payback period (PB). PB is the ratio of increase in total installed costs to the decrease in annual operating costs, where the differences are between the baseline and the substitution technology option. The PB is expressed in years. The Department does not discount costs in this formulation of payback period.

The PB is the amount of time needed to recover through lower operating costs, OC, the additional consumer investment, PC, in increased efficiency. PB is found by solving the equation:

$$\Delta PC + \sum_{t=1}^{PB} \Delta OC_t = 0 \qquad \text{(Equation 5.2)}$$

In general, *PB* is found by interpolating between the two years when the expression in Eq. 5.2 changes sign. If the operating cost is constant, the equation has the simple solution:

$$PB = -\frac{\Delta PC}{\Delta OC} \qquad \text{(Equation 5.3)}$$

Numerically, the PB is the ratio of ΔPC, the difference in purchase (and installation) price between the baseline and the energy-efficient models, to ΔOC, the decrease in annual operating expenditures (including maintenance).

IESNA's Lighting Handbook, 9th edition (2000), presents a calculation method for payback period. Appendix G of this document describes this method and compares it to the proposed calculation method. Appendix G also shows that the payback period methods described here and in the IESNA Handbook are equivalent.

The Department requests stakeholder comments on the proposed calculation method for payback period.

5.6. Life-Cycle Cost Technology Options

The Department will run LCC analyses for the product applications and sectors that appear below.

Table 5-3: Life-Cycle Cost Analyses by Product Application, Sector and Baseline Mercury Vapor Lamp Wattage

Product Application	Sector	MV Baseline Wattage	LCC Table
Indoor, High-Bay	Commercial	400W	Table 5-4
	Industrial	400W	Table 5-4
Indoor, Low-Bay	Commercial	175W	Table 5-5
	Industrial	175W	Table 5-5
Outdoor, Roadway, Architectural	Public Sector	175W	Table 5-6
Outdoor, Roadway, Streetlighting	Public Sector	100W	Table 5-7
		175W	Table 5-8
Outdoor, Area Lighting, Large Area	Commercial	400W	Table 5-9
	Industrial	400W	Table 5-9
Outdoor, Area Lighting, Small Area	Commercial	175W	Table 5-10
	Industrial	175W	Table 5-10
Outdoor, Area Lighting, Security	Residential	175W	Table 5-11
	Commercial	175W	Table 5-11
	Industrial	175W	Table 5-11
Floodlighting, Landscape	Commercial	175W	Table 5-12

The eight product applications are shown in Table 5-4 through Table 5-12. The Department will calculate three replacement options—luminaire replacement, lamp/ballast replacement, and direct lamp replacement–separately for each product application. The Department will analyze replacement options for all of the product applications for each sector (commercial, industrial, public, and/or residential) where they are commonly used. These cases are based on Table 4-5, which summarizes the substitutions for each of the eight product applications.

The Department requests stakeholder comments on the percentage of the market that will choose each substitution technology option (Replace Lamp, Replace Lamp/Ballast, or Replace Luminaire) in Table 5-4 through Table 5-12, in response to the baseline lamp possibly becoming unavailable due to a standard. The Department will use these percentages (replacement weights) to select the most common substitution technology options for the LCC analysis.

Table 5-4: Life-Cycle Cost Technology Options for Product Application 1: High-Bay

Substitution Event	MV System Baseline	Substitution Technology Options	Description
I New Installation	New MV Luminaires	NA	There are no new installations occurring for MV lamps in this product application (see Table 4-5), therefore this substitution event is not considered.
II Lamp Failure	Replace Lamp 400W MV	Replace Lamp 325W MH 400W MH 300W HPS 360W HPS	Compare replacement of a MV lamp with that of a compliant screw-in direct replacement lamp.
		Replace Lamp/Ballast 360W MH 320W PMH 250W HPS	Compare replacement of a MV lamp with that of a compliant lamp and ballast combination utilizing the existing fixture.
		Replace Luminaire 250W MH 250W PMH 200W HPS T-5HO (4x54w) CFL (6x42w)	Compare replacement of a MV lamp with that of a compliant luminaire (lamp, ballast and fixture).
III Ballast Failure	Replace Lamp/Ballast 400W MV	Same as Lamp/Ballast replacement under Lamp Failure	Compare retrofit from a MV lamp and ballast combination to a compliant lamp and ballast combination of similar light output.
		Same as Luminaire replacement under Lamp Failure	Compare retrofit from a MV lamp and ballast combination to a compliant luminaire (lamp, ballast and fixture) of similar light output.

Table 5-5: Life-Cycle Cost Technology Options for Product Application 2: Low-Bay

Substitution Event	MV System Baseline	Substitution Technology Options	Description
I New Installation	New MV Luminaires	NA	There are no new installations occurring for MV lamps in this product application (see Table 4-5), therefore this substitution event is not considered.
II Lamp Failure	Replace Lamp 175W MV	Replace Lamp 150W HPS	Compare replacement of a MV lamp with that of a compliant screw-in direct replacement lamp.
		Replace Lamp/Ballast 100W PMH 150W MH 150W HPS	Compare replacement of a MV lamp with that of a compliant lamp and ballast combination utilizing the existing fixture.
		Replace Luminaire 100W PMH 70W HPS T-8 (3x32w) CFL (4x26w)	Compare replacement of a MV lamp with that of a compliant luminaire (lamp, ballast and fixture).
III Ballast Failure	Replace Lamp/Ballast 175W MV	Same as Lamp/Ballast replacement under Lamp Failure	Compare retrofit from a MV lamp and ballast combination to a compliant lamp and ballast combination of similar light output.
		Same as Luminaire replacement under Lamp Failure	Compare retrofit from a MV lamp and ballast combination to a compliant luminaire (lamp, ballast and fixture) of similar light output.

Table 5-6: Life-Cycle Cost Technology Options for Product Application 3: Roadway Architectural

Substitution Event	MV System Baseline	Substitution Technology Options	Description
I New Installation	New MV Luminaires	NA	There are no new installations occurring for MV lamps in this product application (see Table 4-5), therefore this substitution event is not considered.
II Lamp Failure	Replace Lamp 175W MV	Replace Lamp 150W HPS	Compare replacement of a MV lamp with that of a compliant screw-in direct replacement lamp.
		Replace Lamp/Ballast 100W PMH 150W MH 150W HPS	Compare replacement of a MV lamp with that of a compliant lamp and ballast combination utilizing the existing fixture.
		Replace Luminaire 100W PMH 70W HPS QL 85	Compare replacement of a MV lamp with that of a compliant luminaire (lamp, ballast and fixture).
III Ballast Failure	Replace Lamp/Ballast 175W MV	Same as Lamp/Ballast replacement under Lamp Failure	Compare retrofit from a MV lamp and ballast combination to a compliant lamp and ballast combination of similar light output.
		Same as Luminaire replacement under Lamp Failure	Compare retrofit from a MV lamp and ballast combination to a compliant luminaire (lamp, ballast and fixture) of similar light output.

Table 5-7: Life-Cycle Cost Technology Options for Product Application 4a: Streetlighting (100W)

Substitution Event	MV System Baseline	Substitution Technology Options	Description
I New Installation	New Luminaire	NA	There are no new installations occurring for MV lamps in this product application (see Table 4-5), therefore this substitution event is not considered.
II Lamp Failure	Replace Lamp 100W MV	NA	There is no replacement of a MV lamp with that of a compliant screw-in direct replacement lamp.
		NA	There is no replacement of a MV lamp with that of a compliant lamp and ballast combination utilizing the existing fixture.
		Replace Luminaire 50W HPS	Compare replacement of a MV lamp with that of a compliant luminaire (lamp, ballast and fixture).
III Ballast Failure	Replace Lamp/Ballast 100W MV	NA	There is no retrofit from a MV lamp and ballast combination to a compliant lamp and ballast combination of similar light output.
		Same as Luminaire replacement under Lamp Failure	Compare retrofit from a MV lamp and ballast combination to a compliant luminaire (lamp, ballast and fixture) of similar light output.

Table 5-8: Life-Cycle Cost Technology Options for Product Application 4b: Streetlighting (175W)

Substitution Event	MV System Baseline	Substitution Technology Options	Description
I New Installation	New Luminaire 175W MV	New Luminaire 70W HPS	Compare installation of a MV luminaire with compliant luminaries, producing equivalent light output.
II Lamp Failure	Replace Lamp 175W MV	Replace Lamp 150W HPS	Compare replacement of a MV lamp with that of a compliant screw-in direct replacement lamp.
		Replace Lamp/Ballast 100W PMH 150W MH 150W HPS	Compare replacement of a MV lamp with that of a compliant lamp and ballast combination utilizing the existing fixture.
		Replace Luminaire 100W PMH 70W HPS	Compare replacement of a MV lamp with that of a compliant luminaire (lamp, ballast and fixture).
III Ballast Failure	Replace Lamp/Ballast 175W MV	Same as Lamp/Ballast replacement under Lamp Failure	Compare retrofit from a MV lamp and ballast combination to a compliant lamp and ballast combination of similar light output.
		Same as Luminaire replacement under Lamp Failure	Compare retrofit from a MV lamp and ballast combination to a compliant luminaire (lamp, ballast and fixture) of similar light output.

Table 5-9: Life-Cycle Cost Technology Options for Product Application 5: Large Area

Substitution Event	MV System Baseline	Substitution Technology Options	Description
I New Installation	New MV Luminaires	NA	There are no new installations occurring for MV lamps in this product application (see Table 4-5), therefore this substitution event is not considered.
II Lamp Failure	Replace Lamp 400W MV	Replace Lamp 325W MH 400W MH 300W HPS 360W HPS	Compare replacement of a MV lamp with that of a compliant screw-in direct replacement lamp.
		Replace Lamp/Ballast 360W MH 320W PMH 250W HPS	Compare replacement of a MV lamp with that of a compliant lamp and ballast combination utilizing the existing fixture.
		Replace Luminaire 250W MH 250W PMH 200W HPS	Compare replacement of a MV lamp with that of a compliant luminaire (lamp, ballast and fixture).
III Ballast Failure	Replace Lamp/Ballast 400W MV	Same as Lamp/Ballast replacement under Lamp Failure	Compare retrofit from a MV lamp and ballast combination to a compliant lamp and ballast combination of similar light output.
		Same as Luminaire replacement under Lamp Failure	Compare retrofit from a MV lamp and ballast combination to a compliant luminaire (lamp, ballast and fixture) of similar light output.

Table 5-10: Life-Cycle Cost Technology Options for Product Application 6: Small Area

Substitution Event	MV System Baseline	Substitution Technology Options	Description
I New Installation	New MV Luminaires	NA	There are no new installations occurring for MV lamps in this product application (see Table 4-5), therefore this substitution event is not considered.
II Lamp Failure	Replace Lamp 175W MV	Replace Lamp 150W HPS	Compare replacement of a MV lamp with that of a compliant screw-in direct replacement lamp.
		Replace Lamp/Ballast 100W PMH 150W MH 150W HPS	Compare replacement of a MV lamp with that of a compliant lamp and ballast combination utilizing the existing fixture.
		Replace Luminaire 100W PMH 70W HPS QL 85	Compare replacement of a MV lamp with that of a compliant luminaire (lamp, ballast and fixture).
III Ballast Failure	Replace Lamp/Ballast 175W MV	Same as Lamp/Ballast replacement under Lamp Failure	Compare retrofit from a MV lamp and ballast combination to a compliant lamp and ballast combination of similar light output.
		Same as Luminaire replacement under Lamp Failure	Compare retrofit from a MV lamp and ballast combination to a compliant luminaire (lamp, ballast and fixture) of similar light output.

Table 5-11: Life-Cycle Cost Technology Options for Product Application 7: Security

Substitution Event	MV System Baseline	Substitution Technology Options	Description
I New Installation	New MV Luminaires	NA	There are no new installations occurring for MV lamps in this product application (see Table 4-5), therefore this substitution event is not considered.
II Lamp Failure	Replace Lamp 175W MV	Replace Lamp 150W HPS	Compare replacement of a MV lamp with that of a compliant screw-in direct replacement lamp.
		Replace Lamp/Ballast 100W PMH 150W MH 150W HPS	Compare replacement of a MV lamp with that of a compliant lamp and ballast combination utilizing the existing fixture.
		Replace Luminaire 100W PMH 70W HPS	Compare replacement of a MV lamp with that of a compliant luminaire (lamp, ballast and fixture).
III Ballast Failure	Replace Lamp/Ballast 175W MV	Same as Lamp/Ballast replacement under Lamp Failure	Compare retrofit from a MV lamp and ballast combination to a compliant lamp and ballast combination of similar light output.
		Same as Luminaire replacement under Lamp Failure	Compare retrofit from a MV lamp and ballast combination to a compliant luminaire (lamp, ballast and fixture) of similar light output.

Table 5-12: Life-Cycle Cost Technology Options for Product Application 8: Landscape

Substitution Event	MV System Baseline	Substitution Technology Options	Description
I New Installation	New MV Luminaires	NA	There are no new installations occurring for MV lamps in this product application (see Table 4-5), therefore this substitution event is not considered.
II Lamp Failure	Replace Lamp 175W MV	Replace Lamp 150W HPS	Compare replacement of a MV lamp with that of a compliant screw-in direct replacement lamp.
		Replace Lamp/Ballast 100W PMH 150W MH 150W HPS	Compare replacement of a MV lamp with that of a compliant lamp and ballast combination utilizing the existing fixture.
		Replace Luminaire 100W PMH 70W HPS	Compare replacement of a MV lamp with that of a compliant luminaire (lamp, ballast and fixture).
III Ballast Failure	Replace Lamp/Ballast 175W MV	Same as Lamp/Ballast replacement under Lamp Failure	Compare retrofit from a MV lamp and ballast combination to a compliant lamp and ballast combination of similar light output.
		Same as Luminaire replacement under Lamp Failure	Compare retrofit from a MV lamp and ballast combination to a compliant luminaire (lamp, ballast and fixture) of similar light output.

5.7. Results of the Life-Cycle Cost and Payback Period Analysis

The difference in LCC between the baseline technology and the substitution technology option is the LCC Savings. Normally, the LCC of the substitution technology option is lower than that of the baseline, and the LCC Savings are positive. The results of the LCC Savings will include:

- Increased Total Installed Cost ($)
- Decreased Annual Operating Costs ($)
- Life-Cycle Cost Savings ($)
- Payback Period (years)

6. National Energy Savings and Net Present Value

The Department will calculate national impacts of higher energy-efficiency levels for HID lamps as national energy savings (NES) and net present value (NPV). Figure 6-1 shows the inputs, calculated values, and outputs in the NES analysis.

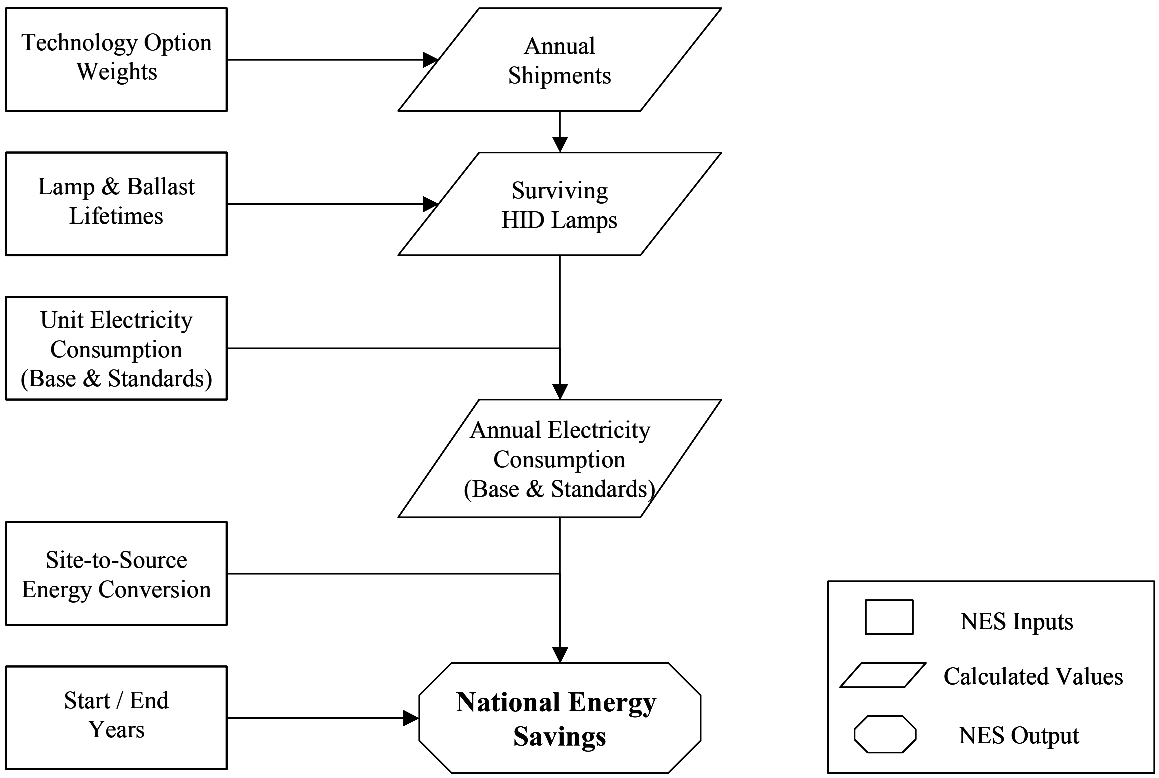


Figure 6-1: Flow Diagram of National Energy Savings Analysis for High Intensity Discharge Lamps

6.1. National Energy Savings Spreadsheet

The Department intends to calculate national energy consumption for each year beginning with the probable effective date of possible standards in 2011 through 2035. The Department will calculate national electrical energy consumption for the base case and a standards case. It will carry out this calculation using a spreadsheet model to multiply shipment forecasts by unit energy savings, calculated for each year and summed over the NES analysis period.

The HID NES spreadsheet will be similar to the NES spreadsheet developed by DOE for analyzing standards for fluorescent lamp ballasts (DOE, 2000) and will provide a forecast of NES and NPV for HID lighting systems.

The Department requests stakeholder comments on this modeling approach to estimating national energy savings.

6.2. Net Present Value

The Department calculates the national NPV of the standards case relative to the base case in conjunction with the national electricity consumption. It calculates annual electricity expenditures from annual electricity consumption by incorporating forecasted electricity prices. The Department will calculate annual total installed costs for HID equipment as the product of costs per unit and the annual unit shipments. Section 5.3.1discusses these costs per unit (lamp, ballast, or luminaire). The difference between the base case and the standards case scenario gives the national electricity bill savings and increased installed costs in dollars. The difference each year between electricity bill savings and increased installed costs is the net savings (if positive) or net costs (if negative). The Department discounts these annual values to the present time and sums them to arrive at a net present value.

Figure 6-2 shows the inputs, calculated values, and outputs in the NPV analysis.

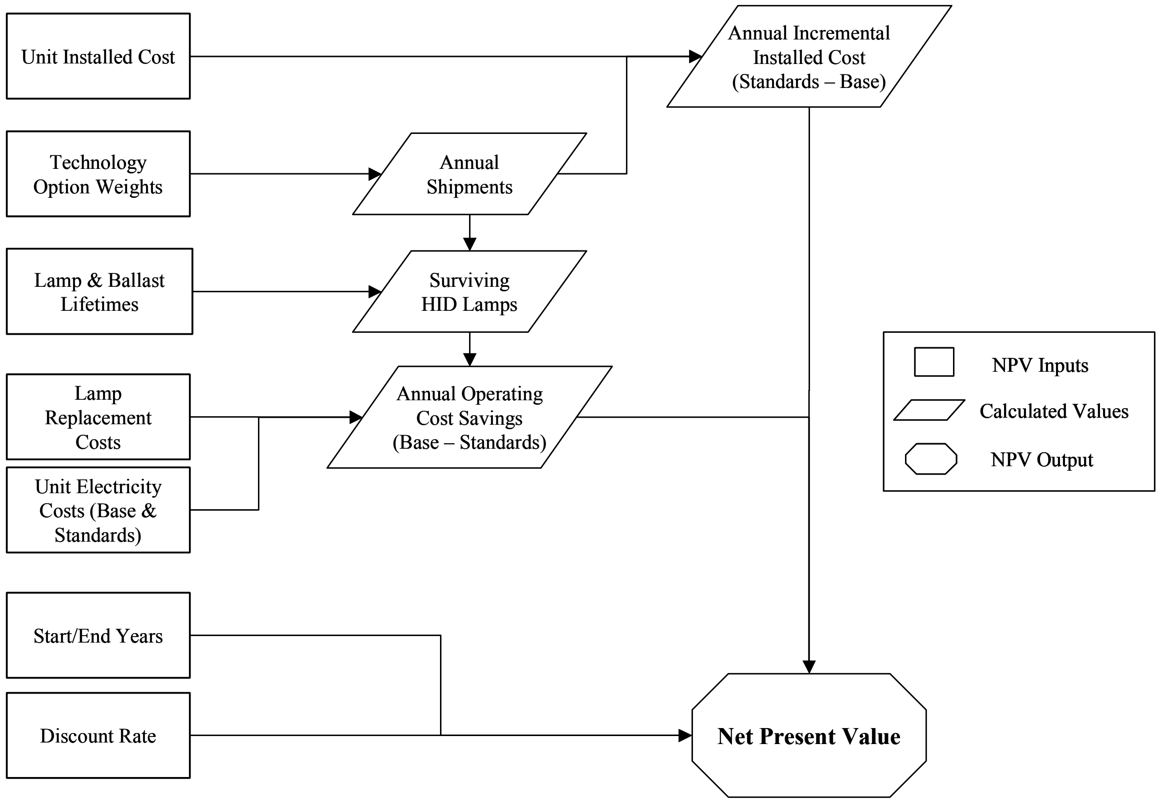


Figure 6-2: Flow Diagram of Net Present Value Analysis for High Intensity Discharge Lamps

Figure 6-3 shows an example (from a previous rulemaking concerning an energy efficient standard for fluorescent lamp ballasts -- DOE, 2000) of the costs and benefits that contribute to NPV, with benefits shown as positive values and costs shown as negative values. The “Equipment Costs Change” bars show the change in total installed costs, changing with shipments year by year. The “Equipment Costs Change” is the change in total installed costs, calculated as the product of annual shipments and the increase in price due to standards. The “Electricity Cost Savings” bars show the change in annual operating costs. The savings from reduced annual operating costs increase over time as shipments increase, until all equipment has been replaced, and then decrease. The decrease occurs because the base case reflects a dynamic market in which more efficient technology will have gained some market share at some point in the future, even without the standards. The middle line (“Net Savings”) is the annual net value (the sum of positive benefits and negative costs). The net present value (not shown) is the sum over the years of discounted annual net costs or benefits. In this example, the discounted sum of benefits is $3.5 billion, while the discounted sum of costs is $0.9 billion, for a Net Present Value of $2.6 billion (1997$ at 7% real).

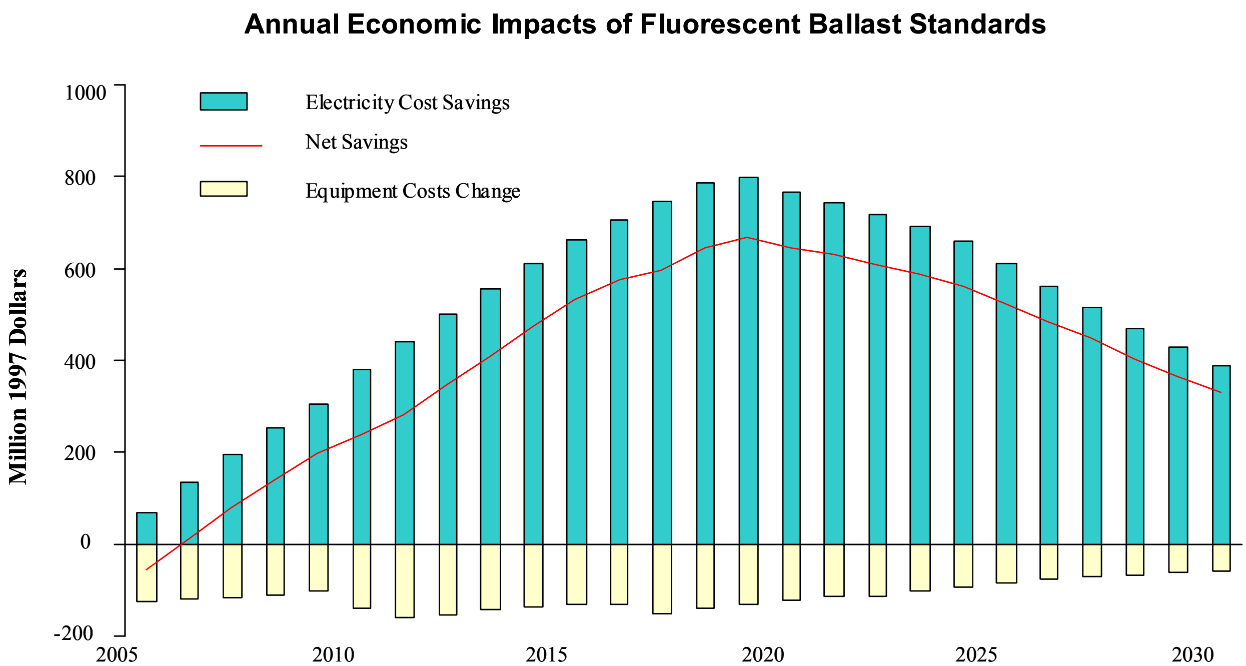


Figure 6-3: Example of Annual Net Costs or Savings Contributing to Net Present Value

6.3. Inputs

In addition to the inputs discussed in the LCC Analysis section, the following additional inputs are required for the NES: a shipments forecast, substitution technology option weights, conversion from site to source energy, time period, and a discount rate for the NPV calculation.

6.3.1. Shipments

For all baseline and substitution technology options, the Department needs to estimate shipment forecasts to calculate the national benefits of standards (electricity savings and NPV). The Department will compare a standards case against the base case. The base case depicts what would happen to electricity consumption and costs over time without new energy conservation standards. The base case predicts HID lamp shipments (by product application and sector) over time, the mix of efficiencies sold in the absence of standards, and how that mix would change over time. To determine the base case, the Department uses data on HID lamp shipments and the substitution technology option weights of the different efficiency levels offered for each. NEMA provided HID lamp shipments data for 1990 through 2002 to the Department for the Market Assessment. Section 2.1 presents these data.

The Department plans to estimate shipments and substitution technology option weights for future years based on statistical analysis of market trends from the NEMA shipments data. Future shipments are uncertain and will depend on market conditions as well as possible changes in technologies, material costs, or other production factors. The Department will deal with this uncertainty by constructing alternative base case scenarios intended to provide reasonable bounds to the uncertainty. Possible scenarios may include a more rapid decline of MV lamp shipments, or a "truncated decline" case, in which MV lamp shipments decline, then stabilize at some lower level that remains constant (or declines more slowly) in future years.

The Department requests comments on methods for estimating forecasts of shipments and on possible scenarios.

For the NES analysis, the Department plans to estimate the percentage of shipments of each major MV wattage that goes to each product application. Table 6-1 shows the MV mogul-based lamps and product applications for which the Department seeks these percentages. The shipments shown in Table 6-1 are NEMA data from Table 2-6. In any column, a black box indicates a product application in which the Department thinks that MV lamps are scarce in that wattage.

Table 6-1: Percent of Mercury Vapor Mogul-Based Lamp Shipments by Wattage and Product Application

Lamp Wattage and Type		100W ED, ET23.5	175W BT, ED28	250W BT, ED28	400W BT, ED37	1000W BT56
Annual Lamp Shipment Estimates[10]		243,000	1,612,000	161,000	326,000	69,000
Product Applications	High-Bay					
	Low-Bay					
	Roadway Architectural					
	Streetlighting					
	Large Area					
	Small Area					
	Security					
	Landscape					
	Other*					
Column Totals		100%	100%	100%	100%	100%

* "Other" represents all the product applications that use MV lamps that are not in the eight product applications that the Department intends to study in this analysis.

The Department asks stakeholders to provide their estimates of the breakdown of MV lamp shipments by wattage and product application shown in Table 6-1. The total of the percentages for each column should add to 100%.

[10]Section 2.1.2 of this report discusses development of these estimates.

Table 6-2 shows the MV mogul-based lamps and the sectors where the Department seeks information on their use. The Department considers that, for each product application, the white boxes in the table represent the sectors where most of these MV lamps are used. In any row, a black box indicates a sector in which the Department thinks that MV lamps may be present, but are scarce.

Table 6-2: Percent of Mercury Vapor Mogul-Based Lamp Shipments by Product Application and Sector

Product Application	Commercial	Industrial	Public	Residential	Totals
High-Bay					100%
Low-Bay					100%
Roadway Architectural			100%		100%
Streetlighting			100%		100%
Large Area					100%
Small Area					100%
Security					100%
Landscape	100%				100%

The Department asks Stakeholders to provide their estimates of the sectoral breakdown of MV lamp shipments for each product application and sector shown in Table 6-2. The total of the percentages for each row should add to 100%.

6.3.2. Substitution Technology Option Weights

If existing technologies cannot meet the new standard, alternative technologies will replace them. For example, MH or HPS systems may replace MV systems. The Department will estimate substitution technology option weights in the standards case for each alternative light source that substitute for the MV systems that were in the base case, based on available time series information. As an example, Table 6-3 presents the substitution technology options for one product application for which the Department needs substitution technology option weights (percentages), for each sector in which the product application operates (see Table 5-2).

The Department asks stakeholders to provide their estimates of the percentage of the market that will choose each Substitution Technology Option for each Product Application in Table 5-4 through Table 5-12. (Substitution Technology Option Weights within each replacement type should total 100%, as shown in the example Table 6-3.)

Table 6-3: Market Shares for Product Application 1: High-Bay (Commercial Sector)

Substitution Event	MV System Baseline	Substitution Technology Options	Substitution Technology Option Weights (%)
II Lamp Failure	Replace Lamp 400W MV	**Replace Lamp**	**(Total = 100%)**
		325W MH	
		400W MH	
		300W HPS	
		360W HPS	
		Replace Lamp/Ballast	**(Total = 100%)**
		360W MH	
		320W PMH	
		250W HPS	
		Replace Luminaire	**(Total = 100%)**
		250W MH	
		250W PMH	
		200W HPS	
		CFL (6x42W)	
		T-5HO (4x54W)	

6.3.3. Conversion from Site to Source Energy

The Department will calculate energy consumption and savings as site energy and then convert them to source energy. The Department proposes to use site-to-source energy conversion factors (from TWh to Quads) from the Annual Energy Outlook, 2003 (EIA, 2003).

6.3.4. National Energy Savings Time Period

The probable start year for possible standards is 2011. The Department assumes that it will complete the Determination analysis in 2004. It would complete a possible rulemaking by 2008, followed by the 3-year phase-in period follows with standards taking effect in 2011. The Department is calculating the NES through the end year of 2035 for consistency with other current DOE rulemakings. In the NPV analysis, the Department includes total installed costs and lifetime operating costs for equipment purchased from 2011 to 2035.

6.3.5. Discount Rate for Net Present Value

Office of Management and Budget requirements set the discount rate at 7% real for calculating NPV, and recommend a sensitivity analysis at 3% real (OMB, 2003).

6.3.6. Cumulative Regulatory Burden

The Department will recognize and seek to mitigate the overlapping effects on manufacturers of amended DOE standards and other regulatory actions affecting the same equipment or companies.

The Department requests comments on related regulatory actions that it should review.

6.4. Results of National Energy Savings and Net Present Value Analysis

The NES and NPV calculations depend on two scenarios—the base case and the standards case. The Department will calculate the impact on energy savings, installed costs, and annual operating costs as the difference between base case and standards case.

Base Case. The Department will create a base case with total shipments extrapolated from current trends. The Department will extrapolate market shares (e.g., for MV, MH, and HPS), with sensitivity cases if needed. As discussed in the Technology and Market Assessment section, the Department will distinguish between the new and renovation markets, since their equipment and labor costs are considerably different.

Standards Case. In the standards case, technologies with efficiencies below the standard level will no longer be available for sale after the effective date. The Department will revise market shares and shipments to reflect the change.

Results will include annual estimates—for years from 2011 to 2035—of energy savings, installed costs, and operating costs. The Department will report cumulative NES and NPV.

Appendix A. Glossary of Terms

Ballast - a device used to obtain the necessary electrical conditions to start and operate an electric-discharge lamp. (IESNA, 2000)

Ballast Efficiency - the measurement of energy-related performance of a ballast. In assessing a ballast in terms of energy efficiency, it may be helpful to look at the losses incurred by the ballast. The Department's analysis will examine the total power dissipation by the ballast at rated conditions, in addition to determining the ratio of the power provided to the lamp and the input power to the ballast. The power dissipation will be given in the unit of watts and the ratio will be given as a percentage of ballast output power to its input power at rated conditions. (IESNA, 2000)

Ballast Factor - The ballast factor quantifies the performance of a ballast with respect to a reference ballast as defined by ANSI (C82) standards documents.

Blackbody - a temperature radiator of uniform temperature whose radiant excitance in all parts of the spectrum is the maximum obtainable from any temperature radiator at the same temperature. Such a radiator is called a blackbody because it absorbs all the radiant energy that falls upon it. All other temperature radiators can be classed as non-blackbodies. Non-blackbodies radiate less in some or all wavelength intervals than a blackbody of the same size and the same temperature. (IESNA, 2000)

Color Rendering Index (CRI) - a metric to gauge the quality of light. Using eight standard color samples under a reference light source, the chromaticity of the samples under the test lamp are compared to the chromaticity of the samples under a reference lamp. A perfect rendering with respect to the reference source is subjectively given a maximum value of 100. The changes (or shifts) in chromaticity are averaged and a single CRI value is determined scaled to the maximum value. A limitation of this metric is that it is only applicable to light sources of the same correlated color temperature (CCT). In other words, CRI values of two light sources with different CCT cannot be compared. For example, comparison of a "cool" lamp and a "warm" lamp provides no useful information. However, the metric does allow for comparison of lamps across different source technologies. For example, the CRI values for a 5000K fluorescent lamp can be compared to a 5000K HID lamp. (IESNA, 2000)

Correlated Color Temperature (CCT) - the absolute temperature of a blackbody whose chromaticity most nearly resembles that of the light source. The metric for color is CCT, given in degrees Kelvin (K). Cooler temperatures (less than 3200K) are referred to as being "warm" in color, while hotter temperatures (in excess of 4000K) are referred to as being "cool" in color. (IESNA, 2000)

Direct Lighting – refers to luminaires that direct 90 to 100% of the emitted light in the general direction of the surface to be illuminated; this term usually refers to light emitted in a downward direction. (IESNA, 2000)

Efficacy - the measure of energy efficiency for lamps, reporting light output per unit of energy input. Its units are lumens per watt (LPW). For example, an electric heater may be very efficient in converting electrical energy to radiant energy, but it has a very low efficacy since the energy conversion does not result in light. So, efficacy provides a metric to compare the energy efficiency of white light sources. However, this does not take into account the contribution of the ballast to the overall efficacy of the lamp/ballast system. (IESNA, 2000)

Fixture - the housing into which a lamp and ballast are installed to create a finished luminaire. The fixture protects the lamp, and usually manages source light distribution.

Fluorescent Lamp – a low-pressure mercury electric-discharge lamp in which a fluorescing coating (phosphor) transforms some of the UV energy generated by the discharge into light. (IESNA, 2000)

Foot-Candle - (fc) is a unit of illuminance equal to 1 lm/ft^2 or 10.76 lux (IESNA, 2000). For this measure of illuminance, one foot-candle is equivalent to the amount of light emitted by a single candle onto a plane orthogonal to the angle of incidence at a distance of one foot from the candle.

Illuminance – (E) is the area density of the luminous flux incident at a point on a surface. This is expressed by the following equation, $E = d\Phi/dA$ (IESNA, 2000). In other words, illuminance is the density of light determined by taking the total amount of light that falls on a plane divided by the total area of the plane.

Incandescent (Filament) Lamp – a lamp in which light is produced by a filament heated to incandescence by an electric current. (IESNA, 2000)

Indirect Lighting – refers to luminaires that direct 90 to 100% of the emitted light away from the surface to be illuminated (generally upward). (IESNA, 2000) A common example of indirect lighting is a torchiere lamp.

Induction Lamp – a fluorescent lamp where the electric discharge is induced by a magnetic field rather than an electric field, as in a fluorescent lamp. Therefore, an induction lamp does not have any electrodes.

Lamp - a generic term for a source created to produce optical radiation. By extension, the term is also used to denote sources that radiate in regions of the spectrum adjacent to the visible. Through popular usage, a portable luminaire consisting of a lamp with shade, reflector, enclosing globe, housing, or other accessories is also sometimes called a lamp. In such cases, in order to distinguish between the assembled unit and the light source within it, the latter is often called a bulb or tube, if it is electrically powered. (IESNA, 2000)

Lamp Lumen Depreciation (LLD) - the intrinsic reduction in light output from start to finish of lamp. Many factors affect this reduction in light output such as the fixture construction and application. For example, the accumulation of dust on the lamp (and fixture) will contribute to the reduction in light output over time. We are concerned only with the loss of light output over time due to non-recoverable intrinsic factors such as the loss of emissive material on the electrodes, change in transmissivity of the arc tube, leakage of gas in the arc tube (IESNA, 2000). For the HID family of lamps, manufacturers often provide mean lumens as a measure of the lamp lumen depreciation. Usually its light output is given at 40% of its rated life. Since no standard exists, caution needs to be exercised when comparing the mean lumen value for different models and manufacturers. The interpretation in the definition of mean lumen may vary among the various manufacturers.

Light - radiant energy that is capable of exciting the retina and producing a visual sensation. Since the energy at each wavelength does not stimulate the human visual system equally, to go from radiant energy to light, it is necessary to factor the contribution of radiant energy from each wavelength by the visibility function of the human eye. That function is defined by the CIE as the photopic visibility function. This effectively limits the useful radiant energy to a very small range in the electromagnetic spectrum called the visible spectrum (wavelengths greater than 380 nanometer and shorter than 780 nanometer). Since it is the distribution of the converted electrical energy in the visible spectrum that determines the efficacy of a light source, a highly-efficient source, capable of converting electrical energy to radiant energy, may not necessarily be a source of high efficacy. (IESNA, 2000)

Lighting Specifier – lighting experts who have the knowledge and authority to decide (specify) which lighting products will provide the desired service for a particular job.

Light Loss Factor - (LLF), the ratio of illuminance for a given area to the value that would occur if a lamp operated at its (initial) rated illuminance output, and no system variation or depreciation had occurred. The light loss factor is used in lighting design calculations to allow for depreciation of light output from a lamp, luminaire, light control elements, or room surfaces, so that a minimum desired level of illuminance is maintained. Formerly called the *maintenance factor*, the LLF had been widely interpreted as the ratio of average illuminance in service to initial illuminance. (IESNA, 2000)

Lumen – (lm) is the SI (metric) unit of luminous flux. Radiometrically, it is determined from the radiant power as in *luminous flux*. Photometrically, it is the luminous flux emitted within a unit solid angle (1 steradian) by a point source having a uniform luminous intensity of 1 candela. (IESNA, 2000)

Luminaire - a complete lighting unit consisting of a lamp or lamps and ballast(s) (when applicable) together with a fixture (housing and parts) designed to distribute the light, to position and protect the lamps, and to connect the lamps to the power supply. (IESNA, 2000)

Mounting Height – the vertical distance between the illuminated surface and the center of the apparent light source of a luminaire. Note, this term is commonly used in association with roadway lighting. (IESNA, 2000)

Rated Life - defined by the Illuminating Engineering Society of North America (IESNA) as the time for 50% of a large group of lamps to cease producing light. From that definition, the rated life of an HID lamp is specified as its cumulative operation time to end of life in hours.

Although that definition is sufficient in terms of absolute life, it is insufficient in evaluating the useful life of the HID lamp. For example, consider a theoretical lamp rated for 100,000 hours of life. After 5,000 hours, the light output has dropped to 50% the initial light output; after 20,000 hours the light output is at 25% the initial light output. By the time the lamp reaches 100,000 hours of operation, the light output may only be 5% of the initial light output. The lamp would have outlived its usefulness in most applications long before it reached the end of its 100,000 hours rated life. Therefore, a discussion of life without consideration to the reduction in light output over operational time is incomplete. (IESNA, 2000)

Reflector Lamp- an incandescent filament or electric-discharge lamp in which the outer blown glass bulb is coated with a reflecting material so as to direct the light (such as R- or ER-type lamps). (IESNA, 2000)

Spectral Power Distribution (SPD) - a pictorial representation of the radiant power emitted by a light source at each wavelength or band of wavelengths in the visible region of the electromagnetic spectrum (360 to 770 nanometers). The CCT and CRI of the light source is determined from the SPD to indicate the perceived color and quality of the light generated by the lamp. (IESNA, 2000)

System Efficacy - the measurement of energy efficiency for a lamp-ballast combination. HID lamps are never used independent of a ballast (with the exception of self-ballasted mercury vapor lamps). The application of system efficacy is the same as for lamp efficacy except it takes into account the contribution of the ballast as it delivers power to the lamp from the main. Multiplying the rated lamp lumens by the ballast factor and dividing the product by total input watts produces a metric for system efficacy. (IESNA, 2000)

Warm-Up and Re-strike Time - the time required for the lamp to reach full light output and the time required for the lamp to restart when extinguished after prolonged operation respectively. Each HID lamp type contains a mixture of a starting gas (e.g., argon, xenon, neon) and some metals and/or halide compounds of metals that, when evaporated into the arc discharge, produce characteristic lines of radiant energy. A certain amount of time is required for the metals and halide compounds to evaporate and attain their optimal vapor pressure. When the arc discharge is extinguished after prolonged operation, the immediate high vapor pressure inside the arc tube would require an inordinately high voltage, many magnitudes greater than its cool-start voltage, to re-establish the arc discharge. Therefore, the arc tube must be allowed to cool so that the vapor pressure will come down to a level where the arc can be restarted. (IESNA, 2000)

Appendix B. Industry High Intensity Discharge Lamp Definitions

This appendix provides the definitions of HID lamps as provided by ANSI (C82.9-1996) and IESNA (Lighting Handbook 9th Edition).

B.1 American National Standards Institute (ANSI) Definition

ANSI C82.9-1996: American National Standard for High-Intensity Discharge and Low-Pressure Sodium Lamps, Ballasts and Transformers - Definitions

3.25 High-intensity discharge (HID) lamp: An electric discharge lamp in which the light producing arc is stabilized by the wall temperature, and has a bulb wall loading in excess of three watts per square centimeter. High-intensity discharge lamps include groups of lamps known as mercury, metal halide, and high-pressure sodium.

3.27 High-pressure sodium (HPS) lamp: A high-intensity discharge lamp in which the major portion of the light is produced by radiation from sodium vapor operating at a partial pressure of about 6.67×10^3 pascals (50 torr) or greater.

3.40 Low-pressure sodium (LPS) lamp: A discharge lamp in which light is produced by radiation from sodium vapor operating at a partial pressure of 0.13 to 1.3 pascals (10^{-3} to 10^{-2} torr).

3.44 Mercury lamp: A high-intensity discharge lamp in which the major portion of the light is produced by radiation from mercury operating at a partial pressure in excess of 1.013×10^5 pascals (760 torr).

3.45 Metal halide lamp: A high-intensity discharge lamp in which the major portion of the light is produced by radiation of metal halides and their products of dissociation in combination with metallic vapors such as mercury.

3.76 Self-ballasted lamp: An arc lamp containing an internal ballast.

B.2 Illuminating Engineering Society of North America (IESNA) Definition

IESNA Lighting Handbook 9th Edition: Chapter 6: Light Sources (p. 6-42 to 6-59)

Page 6-42 High-intensity-discharge (HID) lamps include the groups of lamps commonly known as mercury, metal halide, and high-pressure sodium. The light-producing element of these lamp types is a wall-stabilized arc discharge contained within a refractory envelope (arc tube) with wall loading in excess of 3 W/cm^2 (19.4 W/in^2).

Page 6-43 In mercury lamps, light is produced by the passage of an electric current through mercury vapor. The amount of mercury in the lamp essentially determines the final operating pressure, which is 200 to 400 kPa (29 to 58 lb/in^2) in the majority of lamps.

Page 6-44 Metal halide lamps are similar in construction to mercury lamps, the major difference being that the metal halide arc tube contains various metal halides in addition to the mercury and argon.

Page 6-47 In high-pressure sodium lamps, light is produced by electric current passing through sodium vapor.

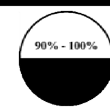
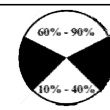
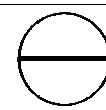
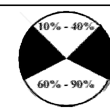
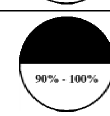
Page 6-55 … these lamps [self-ballasted lamps] do not require an auxiliary ballast.

Page 6-59 In low-pressure sodium discharge lamps, the arc is carried through vaporized sodium. In order to obtain the maximum efficacy of the conversion of the electrical input to the arc discharge into light, the vapor pressure of the sodium must be approximately of 0.7 Pa, which corresponds to an arc tube bulb wall temperature of approximately 260^{o}C.

Appendix C. Existing Classification Systems

The International Commission on Illumination (CIE) specifies a system of classification commonly used today for indoor luminaires (see Table C-1). This system identifies the luminaire type by the proportionality of the upward and downward component of the light.

Table C-1: CIE Classification of Indoor Luminaires

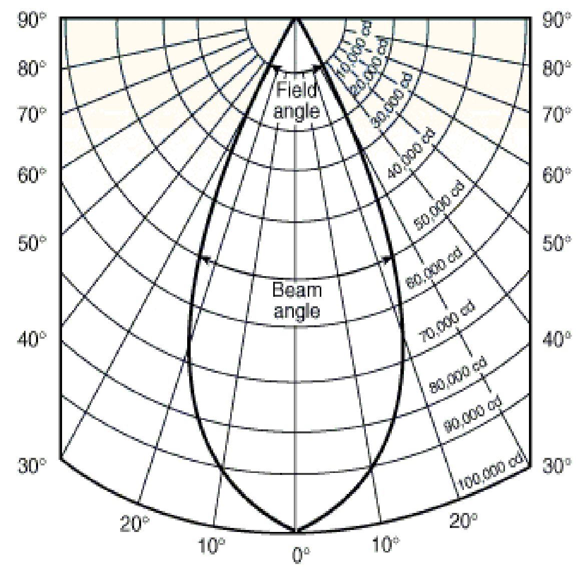
Name	Description	CIE Illustration
Indirect	90 - 100% of light is directed upward	
Semi-Indirect	60 - 90% of light is directed upward	
General Diffuse	Equal portions of the light are directed upward and downward	
Semi-Direct	60 - 90% of light is directed downward	
Direct	90 - 100% of light is directed downward	

Source: IESNA, 2000.

Although HID luminaires have an upward and downward component to their light distribution analogous to this classification system, the CIE system primarily classifies linear fluorescent luminaires.

For outdoor luminaires, NEMA created a classification system based on circular or oval symmetric distribution of light defined in terms of its field angle. The IESNA adopted this system and developed an approved method for photometric testing for this system. Table C-2 summarizes the various types of luminaires and their associated field angles. The field angle is measured between points of 10% of maximum intensity. Table C-2 shows the seven light distributions for this classification system. A numerical value denotes the width of the beam. A single designation based on its symmetrical field angle represents circular patterns. Two values, for horizontal and vertical field angles, represent oval patterns. For example, the illustration in Table C-2 shows an intensity distribution on a polar coordinate system with a maximum intensity of 100,000 candela at zero degrees. The field angle is the value between the points of intersection of the intensity distribution curve and the polar coordinates at 10,000 candelas. This occurs at the 30º mark, resulting in a field angle of 60º. Since 60º lies somewhere between 46º and 70º, this sample is a NEMA Type 4 luminaire.

Table C-2: NEMA Classifications for Luminaires



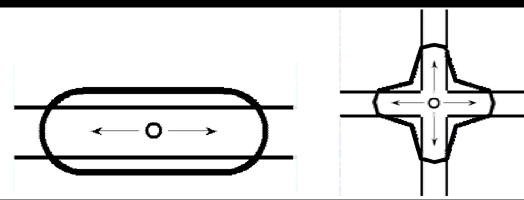
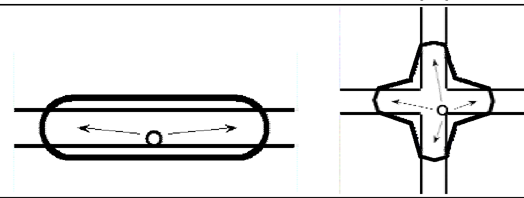
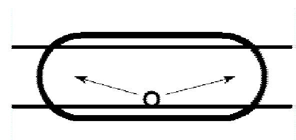
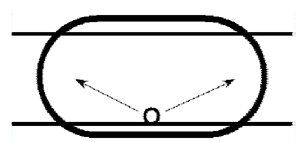
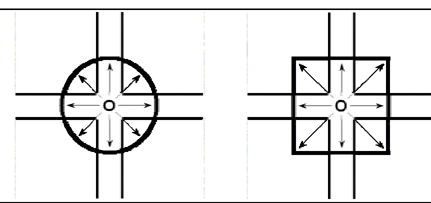
Name	Field Angle (Degrees)
Type 1	10º to 18º
Type 2	18º to 29º
Type 3	29º to 46º
Type 4	46º to 70º
Type 5	70º to 100º
Type 6	100º to 130º
Type 7	130º and up

Reprinted from the IESNA Handbook, 9th Edition 2000, courtesy of the Illuminating Engineering Society of North America, IESNA, 2003.

This system classifies luminaires used in lighting large areas and sports facilities. Most manufacturers have adopted this simple NEMA classification system. However, this system is only useful for classifying luminaries with symmetric oval patterns; it is insufficient for classifying luminaires with complex, asymmetrical light distributions. Therefore, IESNA developed a system to describe more complex systems with non-oval and asymmetrical beam patterns.

IESNA developed a classification system for outdoor luminaires based on the shape of the area illuminated by the luminaire. Table C-3 shows the five classifications based on light distribution pattern: a narrow symmetrical pattern is a Type I luminaire; a narrow asymmetrical pattern is called Type II; a wide asymmetrical pattern is a Type III luminaire; a very wide asymmetrical pattern is a Type IV luminaire; and a circular (square) symmetrical pattern is a Type V(VS) luminaire. Using this classification system, a single pole-mounted luminaire positioned at a corner of a four-way roadway intersection providing a uniform distribution of light limited to the roadway surface would be a Type II luminaire. However, if a luminaire positioned exactly at the center of the intersection provides the same uniform distribution of light, then it would be a Type I luminaire. If the luminaire positioned at the center of an intersection provided a circular symmetrical pattern that spilled beyond the road surface, it would be a Type V luminaire.

Table C-3: IESNA Classification for Roadway Luminaires

Name	Description	Lighting Pattern Illustration
Type I	Narrow symmetrical pattern	
Type II	Narrow asymmetric pattern	
Type III	Wide asymmetric pattern	
Type IV	Very Wide asymmetric pattern	
Type V (Type VS)	Circular symmetrical pattern (Square symmetrical pattern)	

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This system classifies luminaires used in roadway applications. Although systems such as these, based on light distribution, are more than adequate in identifying luminaires for their specific applications, it is insufficient for classifying all luminaires that use HID sources.

Appendix D. Non-regulatory Incentive Programs

D.1 California Incentive Programs

The Modesto Irrigation Department (MID) manages a regional program called Commercial Power Saver 2003. This program has, as one of its objectives, the promotion of energy-efficient HID lighting. The equipment promoted under this program includes pulse-start MH fixtures for interior applications and pulse-start MH and HPS fixtures for exterior applications. To be eligible, the program requires that HID fixtures must replace existing incandescent, mercury vapor, standard MH, HPS or T-12 fluorescent fixtures. Rebates are available based on lamp wattage – for indoor luminaires, the program offers $25 per fixture for installing a pulse-start MH to replace a fixture that consumes 175W or less. And, for interior fixtures that consume more than 175W, the program offers a $40 incentive. For exterior applications, the program offers $10 per fixture for installing a pulse-start MH or HPS fixture in place of a fixture that consumes 175W or less. Similarly, the programs offer $20 per fixture for upgrading exterior fixtures that consume more than 175W. For more information about this program, please contact Zane Williams, MID, tel: 209-526-7458, zanew@mid.org.

The Sacramento Municipal Utility District (SMUD) manages a Commercial and Industrial Retrofit Program that seeks to reduce the peak load demand of commercial and industrial customers. This program focuses on interior HID lighting and offers $225 per average kW saved from 1-9 p.m., Monday through Friday. Incentives are offered for retrofits only. For more information, contact Robert Chen, SMUD, tel: 916-732-7470.

Three electric utilities in California, Pacific Gas and Electric, San Diego Gas and Electric and Southern California Edison, jointly manage a state-wide program called the Express Efficiency Lighting Program. This initiative seeks to promote energy-efficient lighting retrofits, such as MH (including pulse-start) and HPS fixtures. MH or HPS lamps must have an efficacy greater than or equal to 60 LPW for compact sources (less than or equal to 100 watts) and 80 LPW for standard or larger sources (greater than 100 watts). The program concentrates on promoting interior and exterior HID fixtures to replace existing incandescent or MV fixtures. In order to be eligible, interior pulse-start MH fixtures must replace existing standard MH lamps and ballasts, incandescent or MV lamps having a minimum of 400 watts. The pulse-start MH lamps can have a maximum 350 watts. The rebates offered are shown in Table D-1. For more information, contact Carol Harty, PG&E, tel: 415-973-2256, carh8@pge.com or Charles Middleton, PG&E, tel: 415-973-4008, cem6@pge.com.

Table D-1. Express Efficiency Lighting Program Incentives (California)

Replacement Lamp Wattage	Incandescent Replacement	MV Replacement
Interior HID Fixtures		
0-35 watts	$25	$23
36-70 watts	$32	$30
71-100 watts	$40	$38
101-175 watts	$40	$38
176-250 watts	$40	$38
251-400 watts	$50	$48
Exterior HID Fixtures		
0-100 watts	$12	$11
101-175 watts	$16	$15
>= 176 watts	$25	$24
Interior Pulse-Start MH Fixture		
-	$45	-

The Los Angeles Department of Water and Power (LADWP) manages the Commercial Lighting Efficiency Offer. This program seeks to promote energy-efficient lighting retrofits, specifically HPS and MH. The LADWP offers a rebate of $37 per fixture for replacing MV or incandescent lighting with HPS or MH. The rebate requires pre-approval from LADWP. For more information, contact Simone Taylor, LADWP, tel: 213-367-4046, simone.taylor@ladwp.com

D.2 Connecticut Incentive Programs

Northeast Utilities manages an Express Rebate Program which works to promote energy-efficient lighting in retrofit applications. This program promotes pulse-start MH retrofit kits by offering a rebate of $45 per fixture. In order to be eligible, the installation must be a retrofit of a higher wattage MV, MH or HPS luminaire. For more information, contact David Bebrin, Northeast Utilities, tel: 860-832-4712, bebridj@nu.com.

United Illuminating manages an Energy Blueprint Program with the objective of promoting energy-efficient lighting in renovation and new construction projects. The equipment promoted includes HPS and MH technologies through incentives based on exceeding the ASHRAE 90.1-1999 lighting density standards (watts per sq. ft). Incentives provided are $25 per qualifying fixture or 0.06/sq. foot for each tenth of a watt below the qualifying baseline up to a maximum of $0.24/sq. foot. For more information, contact Roy Haller, United Illuminating, tel: 203-499-2025; roy.haller@uinet.com

D.3 Florida Incentive Programs

Florida Power and Light (FP&L) manages a Commercial/Industrial Lighting Program that works to reduce the utility's peak demand from 3 pm to 6 pm during summertime weekdays. The equipment promoted under this program includes hard-wired luminaires based on HPS, LPS and MH technologies. FP&L offers $75 per kilowatt saved for high permanency, major fixture lighting modifications. For more information, please contact Matt Macon, Florida Power & Light, tel: 561-640-2580, matt_macon@fpl.com.

D.4 Massachusetts Incentive Programs

National Grid, consisting of member utilities Massachusetts Electric, Nantucket Electric and Granite State Electric, manages a regional program to promote energy efficient pulse-start MH fixtures in new construction projects. These programs are called Design 2000 Plus Program and the New Equipment and Construction Program. National Grid offers a $10-15 incentive per eligible fixture. For more information, please contact Fouad Dagher, National Grid, tel: 508-303-7231, fouad.dagher@us.ngrid.com or James Hurst, National Grid, tel: 603-443-4235.

Nstar, servicing more than 100 eastern Massachusetts communities, manages a Construction Program and Retrofit Program that aims to promote energy-efficient lighting in retrofit and new construction projects. The equipment promoted by this program includes pulse-start MH fixtures for new installations and pulse-start MH and HPS fixtures for retrofit applications. The incentives offered are as follows: for new construction, a pulse-start MH fixture receives a $10 subsidy; for retrofit installations, a pulse-start MH lamp and ballast kit receives $45, a new pulse-start MH luminaire receives $80 and a new HPS luminaire receives a $100 incentive. For more information, contact Timothy Lee, NStar, tel:781-441-3128, timothy_lee@nstaronline.com

D.5 New Hampshire Incentive Programs

Granite State Electric manages an energy-efficient lighting program for retrofit applications. The equipment includes pulse-start MH fixtures, pulse-start MH lamp and ballast kits, and HPS fixtures. In order to qualify for the incentive, each fixture must meet a minimum watt reduction criterion, based on the difference between the existing and replacement luminaires. The incentives provided are $40 for a pulse-start MH lamp and ballast kit that reduces wattage consumption by 29 watts or more; a $70 incentive for a pulse-start MH lamp that reduces wattage consumption by 51 watts or more; and a $70 incentive for HPS fixtures that reduce fixture energy consumption by 41 watts or more. For more information, contact Fouad Dagher, National Grid, tel: 508-303-7231, fouad.dagher@us.ngrid.com or James Hurst, National Grid, tel: 603-443-4235

D.6 New York Incentive Programs

The New York State Energy Research and Development Authority (NYSERDA) manages a Smart Equipment Choices Program that seeks to promote energy-efficient lighting in retrofit applications. The target equipment of this program include HPS fixtures for both interior and external applications, and pulse start MH for interior use. Table D-2 shows the incentive levels and minimum lamp efficacies for the eligible HID fixtures. For more information, contact Cullen O'Brien, NYSERDA, tel: 518-862-1090 ext. 3414, cmo@nyserda.org.

Table D-2: NYSERDA Incentives for Smart Equipment Choices Program

Fixture Type	Incentive per Fixture	Minimum Mean Lamp Efficacy (lm/W)
Pulse Start Metal Halide Fixtures for Interior Use		
Less than or equal to150 Watts	$30	40 LPW
Between 150 and 400 Watts	$38	75 LPW
Greater than or equal to 400 Watts	$45	85 LPW
High Pressure Sodium Fixtures		
Less than or equal to100 Watts	$20	55 LPW
Between 100 and 400 Watts		80 LPW
Greater than or equal to 400 Watts		100 LPW
Non-Pulse Start Metal Halide		
Greater than 1200 Watts	$55	91 LPW

The Long Island Power Authority manages a Commercial Construction Program to promote energy-efficient lighting in new construction projects. This program works to promote pulse-start MH lamps and ballasts, where lamps must have a minimum efficacy of 60LPW for small sources (less than 100 Watts) and 80 LPW for sources greater than 100 watts. An incentive of $30 per fixture is offered. For more information, contact Scott Scherer, LIPA, tel: 631-436-5769, sscherer@keyspanenergy.com.

D.7 Oregon Incentive Programs

The Energy Trust of Oregon manages a State-wide program called the Building Efficiency Program. This program aims to promote energy-efficient lighting upgrades that incorporate HPS or MH fixtures. The Energy Trust offers rebates for replacing MV and incandescent lighting with HPS or MH fixtures - $25 for a HPS or MH fixture less than 175 watts; and $30 rebate for a HPS or MH fixture greater than 175 watts. For more information, please contact Will Miller, Energy Trust of Oregon, tel: 503-243-7844, wmiller@aspensys.com.

D.8 Vermont Incentive Programs

Efficiency Vermont, a state-wide non-profit organization funded out of an efficiency charge applied to the electricity bill, manages a program called Commercial Energy Opportunities. This program works to promote energy-efficient lighting in retrofit projects, specifically pulse-start MH lamps and ballasts. Incentives of $25 per fixture are offered. For more information, contact Art Sousa, Efficiency Vermont, tel: 1888-921-5990, asousa@veic.org

D.9 Washington Incentive Programs

Seattle City Light manages a program called Energy Smart Services Financial Incentives that work to promote energy-efficient lighting in new installations. This program focuses on HPS and MH lamps, and offers $0.13 per annual kWh saving for upgrading a light source to HPS or MH. For more information, please contact Surinder Rekhi, Seattle City Light, tel: 561-640-2551, rekhi.s@seattle.gov.

Appendix E. High Intensity Discharge Lamp Ballasts

E.1 High Intensity Discharge Lamp Ballasts

HID lamp ballasts are required to start the lamp, regulate the operating current, and provide the appropriate voltage to sustain the arc discharge. For HPS and pulse-start MH lamps, an additional ignitor circuit is required to generate the high-voltage starting pulse necessary to initiate the arc discharge. Typical input voltages for HID lighting systems are 120V, 208V, 240V, and 277V, of which 120V and 277V are the most popular. The Department obtained descriptions of each ballast type from Advance Transformers: Pocket Guide to HID Lamp Ballasts (Advance, 2003a); they are summarized below.

E.1.1 Electronic Ballasts

Electronic ballasts are not common in HID lighting applications. Electronic ballasts are only manufactured and sold for pulse-start MH lamps, operating these lamps either with alternating current (AC) or direct current (DC). Manufacturers state that DC operation of the lamps provides improved performance in a smaller package – that is, it results in a higher power factor, less heat, better power regulation, and lower maintenance costs, and it saves energy. If a DC electronic HID ballast is installed, it must be used with an HID lamp designed for DC operation. Electronic ballasts for AC systems are also manufactured and sold; however, these lamp-ballast combinations must operate as a matched pair – meaning a ballast must be manufactured to operate a specific lamp, or premature failure may result. AC-operated electronic ballasts generate an acoustic resonance that causes photometric and electrical problems contributing to premature lamp failure (Lee, 2001). These technical issues have not been fully resolved yet, and have therefore delayed the widespread availability and use of electronic ballasts for HID lamps.

However, once these technological hurdles have been addressed, electronic ballasts will provide significant improvement in performance and function over existing magnetic ballasts. For example, electronic ballast high-frequency ignition is expected to reduce blackening on the arc tube wall, reducing lumen depreciation, and contributing to better color stability and longer lamp life. Manufacturers also state that ballast losses will be dramatically reduced with a shift to electronic ballasts. Finally, continuous dimming of HID sources is more easily done with electronic ballasts. For example, electronic ballasts today can dim a MH lamp down to 33% of rated lamp output. (NLPIP, 2003)

E.1.2 Reactor Ballasts

The reactor-type ballast may be the most simple, efficient, and economic solution to ballasting HID lamps. Efficiencies of 5% can be achieved with this configuration. However, it comes with some limitations that need to be considered. The input voltage must meet the starting voltage requirements of an HID lamp. Since most MV lamps and probe-start MH lamps are designed to start approximately at 240V, reactor ballasts may be employed where the main input voltage is greater than 240V. So, if a 120 V main is to be used, it may not provide sufficient voltage to start or operate the lamp. Power factor is a nominal 50% for these ballasts;

it can be improved to about 90% with the addition of a capacitor across the input terminals. Power regulation is poor in these units. For a 5% swing in input voltage, the lamp wattage will vary by 12%. Also, these ballasts will draw substantially higher current during warm-up and/or open circuit operation. Therefore, the power distribution system must provide ample current capacity for this condition. These ballasts are also known as “choke” or “lag” ballasts.

E.1.3 High Reactance Autotransformer Ballasts

The reactor ballast evolved into the high reactance autotransformer (HX). This ballast employs two coils, primary and secondary, which transform the input voltage to the required level. Since the two coils share common windings, is the system is called an autotransformer. This transformation of the input voltage allows this ballast to operate MV, probe-start MH, and LPS from any input voltage. The ballast raises the voltage up to the required levels for the lamp it will operate via the primary and secondary windings. Otherwise, the operating characteristics are identical to the reactor ballast. Efficiencies of 5% to 10% can be expected from this configuration. These ballasts are also sometimes referred to as “lag” ballasts.

E.1.4 Constant Wattage Autotransformer Ballasts

The most widely-used circuit is the constant wattage autotransformer (CWA). It offers the best compromise between cost and performance. When employed in MV systems, it offers very good power regulation; a 10% change in line voltage will only result in a 5% change in lamp wattage. For MH systems, the CWA ballast offers a unity change in lamp wattage to changes in line voltage. Furthermore, input current during warm-up does not exceed current at steady-state operation. Once again, a capacitor is used for no other purpose than power factor correction. Efficiencies of 5% to 10% can be expected from this configuration. For MH and HPS, these ballasts are sometimes referred to as “lead peak” ballasts.

E.1.5 Constant Wattage Ballasts

The constant wattage isolated transformer (CW) ballast, referred to as regulated or premium constant wattage, currently provides the best lamp regulation. Its operational characteristics are similar to the CWA. However, when used with MV lamps, a 13% change in line voltage only results in a 2% change in lamp wattage. Furthermore, because the lamp circuit is completely isolated from the primary coils, this topology offers a safety factor against the danger of shock. Efficiencies as low as 15% can be expected from this configuration. These ballasts are also known as “magnetic regulator” or “regulated lag” ballasts.

E.1.6 Ignitors for High Intensity Discharge Ballasts

Ignitors are used in the ballast circuit for most HPS lamps and some MH lamps (e.g., pulse-start MH). The ignitor starts cold lamps by first providing a high enough voltage for ionization of the gas to produce a glow discharge. To complete the starting process, the starting pulse to sustain an arc through a glow-to-arc transition must provide sufficient power. The range of pulse voltages to start cold lamps is 1 to 5 kV, usually provided by an electronic resonant circuit that applies multiple pulses to the lamp when the circuit is energized. The circuit turns itself off after the lamp starts by either sensing the reduction in open-circuit voltage or, with some ignitors, shutting itself off after a fixed period of time.

Instant restarting of hot lamps can be accomplished by increasing the ignition voltage. However, most HID lamps require extremely high voltage pulses of 10 to 70 kV. To reduce the voltage-to-ground values, ignitor circuits apply opposing pulses simultaneously to both ends of the lamp. Most instant-restart lamps are of double-ended construction to minimize arc-over between lead wires, internal supports, or base contacts. These high-voltage starting pulses normally are applied in one or several short bursts, using the open-circuit voltage reduction on restart to turn off the ignitor.

Under normal conditions, an ignitor actually operates for only a few cycles, once each day, when the lights are started. Even if the lights were turned off momentarily, once each day, it requires only about one minute of pulsing by the ignitor to restrike the lamp. Assuming an ignitor case temperature of 90ºC (worst case), an operating period of one minute per day would total only about five hours of actual operation per year. Since average ignitor life at 90ºC is a total of 800 hours, the use of five hours per year is an insignificant portion of the total time. However, ignitor life can be used up at a significant rate when an inoperative lamp remains in an energized socket for extended periods of time. Assuming a very severe application with a 75ºC case temperature, a total of 10,000 hours of continuous pulsing can be expected. If it were pulsing 24 hours per day, this would result in a total ignitor life of just over one year.

Appendix F. Product Availability Tables

The following tables list product availability for HID general service lamps from all NEMA members. For the purposes of this document, general service HID lamps are limited to 'medium and mogul' base types. Column headings in the tables are defined as follows:

Rated Lamp Power: wattage range from 0 to 2000 watts.

Manufacturer: Limited to NEMA members GE, Philips, Sylvania, Venture, Ushio, and EYE.

Bulb Designation: ANSI designation for bulb shape and size. Nomenclature is a letter or letters indicating the shape followed by numbers indicating max bulb diameter.

Coating: Only interested if it has it or not (clear or coated / diffuse).

Base Type: The metal coupling connecting the lamp to the socket (either mogul or medium).

ANSI Ballast Code: Electrical operating designation of lamp which matches the ballast. Nomenclature is a letter indicating lamp classification followed by numbers representing key electrical characteristics of the lamp.

Lamp Life: Given in operating hours determined when half of a large group of lamps operated at standard test conditions have failed.

Initial Light Output: Lamp light output after 100 hours of seasoning.

Mean Light Output: Lamp light output after a period of time, usually at 40% rated life. (Note that GE lamps are given at 50% rated life for their MV, HPS and LPS).

CCT: Correlated Color Temperature - Color appearance of lamp.

CRI: Color Rendering Index - relative index of lamp ability to render color.

Table F-1: Product Availability: Mercury Vapor Lamp (1 of 2)

Rated Lamp Power(Watts)	Manufacturer	Bulb Designation	Coating	Base Type	ANSI Ballast Code	Lamp Life (Hours)	Initial Light Output (Lumens)	Mean Light Output (Lumens)	CCT (Kelvin)	CRI
40	GE	B17	Clear	Med	H45	6000	V: 1140 H: 1575	V: 910 H: 1250	3900	50
50	Eye	E17 R20 R30	Clr/Ctd Frosted Frosted	Med	H46	8000	1650-1900	1320-1520	4100-5700	25-40
	GE	B17	Coated	Med	H46	6000	V: 1140 H: 1575	V: 910 H: 1250	3900	50
	Sylvania	E17	Coated	Med	H45 H46	24000+	1580	1300	4000	45
	Philips	ED17	Clear	Med	H46	24000+	1580	1260	3200	45
75	Eye	E17	Clr/Ctd	Med	H43	16000	2700-3000	2160-2400	4100-5700	25-40
	GE	B17	Coated	Med	H43	16000	2700	2250	3900	50
	Sylvania	E17	Coated	Med	H43	24000+	2700	1800	4300	45
	Philips	ED17	Clear	Med	H43	24000+	2800	2250	3200	45
80	Eye	E21	Coated	Med	-	16000	3600	2880	4100	40
100	Eye	E17 E24 R30 RD40	Clr/Ctd Clr/Ctd Diffuse Diffuse	Med Mog Mog Mog	H38	24000	4000-4500	3200-3600	4100-5700	25-40
	GE	A23.5 B17 ED23.5 R40	Clr/Ctd Coated Clr/Ctd Clr/Ctd	Med Med Mog Med	H38	18000-24000+	3700-4000	2400-2600	3800-5700	15-50
	Sylvania	E17 ET23.5 PAR38 PAR38 R40	Coated Clr/Ctd Clear Clear Coated	Med Mog Med Med Med	H38 H44	24000+	4000-4100	3000-3560	4000-5900	20-45
	Philips	A23 ED23.5 R40	Clear	Med Mog Med	H38	24000+	4100-4400	3400-3450	3700-7000	20-45
125	Eye	E24 R40	Coated Clear	Mog Med	H42	24000	6250	5000	4100	40
175	Eye	BT28 RD40	Clr/Ctd Diffuse	Mog Med	H39	24000	7800-8900	6240-7120	4100-5700	25-40
	GE	ED28 RD40 RD40	Clr/Ctd Clr/Ctd Clear	Mog Med Mog	H39	24000+	7800-7850	6800-6830	3900-5700	15-50
	Sylvania	BT/ED28 R40	Clr/Ctd Coated	Mog Med	H39	24000+	7700	7150	4000-5900	22-45
	Philips	ED28 R40	Clr/Ctd Clear	Mog Med	H39	24000+	7900-8500	7400-7600	3700-6800	20-45

Table F-1: Product Availability: Mercury Vapor Lamp (2 of 2)

Rated Lamp Power(Watts)	Manufacturer	Bulb Designation	Coating	Base Type	ANSI Ballast Code	Lamp Life (Hours)	Initial Light Output (Lumens)	Mean Light Output (Lumens)	CCT (Kelvin)	CRI
250	Eye	BT28 R63 R52	Clr/Ctd Clear Clear	Mog	H37	24000	12000-13700	9600-10960	4100-5700	25-40
	GE	ED28	Clr/Ctd	Mog	H37	24000+	11000-11200	8250-8400	3900-5700	15-50
	Sylvania	BT/ED28	Clr/Ctd	Mog	H37	24000+	10800-12500	10000	4000-5900	22-45
	Philips	ED28	Clr/Ctd	Mog	H37	24000+	11700-13000	9650-10700	3700-6700	20-45
400	Eye	BT37 R63 R57	Clr/Ctd Clear Clear	Mog	H33	24000	21000-24000	16800-19200	4100-5700	25-40
	GE	BT37 ED37 R52 R60 T16	Coated Clr/Ctd Coated Coated Clear	Mog	H33	12000-24000+	20000-22600	13400-18200	3900-5700	15-50
	Sylvania	BT37 T16	Clr/Ctd Coated	Mog	H33	12000-24000+	18700-23000	16000-16500	4000-5900	16-45
	Philips	ED37 R57 R60	Clr/Ctd Clear Clear	Mog	H33	24000+	21000-23000	18900-19100	3700-6500	20-45
700	Eye	BT46	Coated	Mog	H35	24000	44000	35200	4100	40
	Philips	BT46	Clear	Mog	H35	24000+	43000	33600	3700	45
1000	Eye	BT56 R88	Clr/Ctd Clear	Mog	H36	24000	58000-64000	46400-51200	4100-5700	25-40
	GE	BT56 BT56	Clr/Ctd Coated	Mog	H34 H36	16000-24000+	57000-58300	28500-29200	3900-5700	15-50
	Sylvania	BT56	Clr/Ctd	Mog	H34 H36	16000-24000+	55000-58000	44000-50000	4000-5900	22-45
	Philips	BT56	Clear	Mog	H34 H36	16000-24000+	56700-63000	42800-48400	3700-6300	20-45

Table F-2: Product Availability: Self-Ballasted Mercury Vapor Lamp

Rated Lamp Power(Watts)	Manufacturer	Bulb Designation	Coating	Base Type	Lamp Life (Hours)	Initial Light Output (Lumens)	Mean Light Output (Lumens)	CCT (Kelvin)	CRI
100	Eye	E21	Coated	Med	6000	1100	830	3200	60
160	Eye	E24 R40 RSP38	Coated Frosted Clr/Ctd	Med	8000-12000	2550-3100	1910-2330	3200-3300	60
	GE	ED24	Coated	Med	12000	2300	1600	3900	50
	Philips	E23	Clear	Med	12000	2800	2250	3300	50
250	Eye	E28 R40	Coated Frosted	Med Mog	12000	5000-5700	3750-4280	3200-3300	50
	GE	ED28	Coated Coated	Med Mog	12000	5000	3750	3900	50
	Philips	E28	Clear	Med Mog	12000	5990	4790	3300	50
300	Eye	R40	Frosted	Med Mog					
450	Eye	BT37 R57	Coated Frosted	Mog	16000	10000-11500	7500-8630	3200-3300	50
	GE	BT37	Coated	Mog	16000	9100	8280	3900	50
	Philips	BT37	Coated	Mog	16000	9700	8300	3300	50
750	Eye	BT46 R57	Coated Clr/Fr	Mog	16000	19000-22000	14250-16500	4000	40-45
	GE	B57	Coated	Mog	16000	14000	11200	3900	50
	Philips	R57	Coated	Mog	16000	14000-17300	N/A	3300-4000	40-50

Table F-3: Product Availability: Probe-Start Metal Halide Lamp (1 of 3)

Rated Lamp Power(Watts)	Manufacturer	Bulb Designation	Coating	Base Type	ANSI Ballast Code	Lamp Life (Hours)	Initial Light Output (Lumens)	Mean Light Output (Lumens)	CCT (Kelvin)	CRI
50	Eye	ED17N	Clr/Ctd	Med	M110	10000	3000-3450	1820-1900	2900-3000	70
	Sylvania	E17	Clr/Ctd	Med	M110	V: 15000 H: 10000	3200-3450	1750-2000	2900-3000	70
	Venture	EDX17	Coated	Med	DC	10000	5300	4000	3400	70
70	Eye	ED17N	Clr/Ctd	Med	M98	15000	4800-5200	3600-3900	2900-3000	75
	Sylvania	E17	Clr/Ctd	Med	M85	V: 7500-15000 H: 6000-10000	4700-6000	3100-4900	2900-4200	75-85
	Venture	R40 PAR64 PAR56 PAR38	Clear Coated Clear Clear	Med Mog Mog Med	M85	3000-10000	5200-5600	3400-3600	3000-4200	65-75
75	Ushio	E26	Coated	Med	M98	10000	5000-6000	3550	3000-4200	70
100	Eye	ED17	Clr/Ctd	Med	M90	10000-15000	7900-8500	5800-6400	2900-4200	65-75
	Sylvania	E17	Clr/Ctd	Med	M90	V: 7500-15000 H: 6000-10000	7700-8500	5525-7500	2900-4200	75-82
	Ushio	R								
	Venture	R40 PAR64 PAR56 PAR38	Clear Coated Clr/Ctd Clear	Med Mog Mog Med	M90	3000-10000	9000	5900	3200-4200	65-70
148	Venture	EDX17	Coated	Med	DC	10000	13500	11500	3400-4500	70
150	Eye	ED17N	Clr/Ctd	Med	M102	15000	12000-13300	9000-10000	2900-3000	75
	GE	ED28	Clr/Ctd	Mog	M57	V: 1000-10000 H: 7500	V: 10000-13500 H: 10900-11500	V: 8000-11000 H: 6900-7200	3000-5000	65-80
	Sylvania	BT28 E17	Clear Clr/Ctd	Mog Med	M107 M102	V: 9000-15000 H: 6000-10000	V: 11000-13000 H: 11000-12500	V: 7500-11000 H: 8500-9500	2900-4200	65-88
	Philips	ED17	Clr/Ctd	Med	M107	10000-12000	11250-12500	7900-8500	3400-4200	65-80
	Ushio	R								
	Venture	PAR56 PAR64	Clr/Ctd Coated	Mog	M102 M81	6000-1000	11250-14000	8400-10500	3000-4200	65-70
175	Eye	BT28 ED28 ED17	Clr/Ctd	Mog Mog Med	M57	U: 10000 V: 10000 H: 6000	U: 12900-15000 V: 14000-15000 H: 13500-14000	U: 8200-11000 V: 10500-11000 H: 10000-10500	3800-4200	65-70
	GE	BD17 ED28 PAR38	Clr/Ctd Clr/Ctd Clear	Med Mog Med	M57	V: 10000 H: 6000	V: 12000-15000 H: 10300-119000	V: 7600-8800 H: 6500-7900	3000-4000	65-70
	Sylvania	BT28 ED17	Clr/Ctd	Mog Med	M57	V: 7500-10000 H: 7500	V: 11800-15000 H: 11080-12800	7600-10800	3200-4200	65-70
	Philips	ED17 ED28 PAR38	Clr/Ctd Clr/Ctd Clear	Med Mog Med	M57	10000	12000-15000	7560-12000	3200-4300	65-70
	Venture	ED17 ED28 R40 T15	Clr/Ctd Clear 	Med Mog Med Mog	M57	7500-10000	12000-15000	8600-12000	3200-5200	65-70

Table F-3: Product Availability: Probe-Start Metal Halide Lamp (2 of 3)

Rated Lamp Power(Watts)	Manufacturer	Bulb Designation	Coating	Base Type	ANSI Ballast Code	Lamp Life (Hours)	Initial Light Output (Lumens)	Mean Light Output (Lumens)	CCT (Kelvin)	CRI
250	Eye	BT28 ED28	Clr/Ctd	Mog	M58	U: 10000 V: 10000 H: 6000	U: 19800-20800 V: 20750-21500 H: 19650-19700	U: 12600-13500 V: 17200-17250 H: 13800-15850	3800-4200	65-70
	Sylvania	BT28 ET18 T14.5	Clr/Ctd Clear Clear	Mog Mog Mog	M58	9000-10000	V: 17200-23000 H: 19500-20000	V: 12500-17500 H: 13500-16000	3200-5200	65-93
	Philips	ED28 T15	Clr/Ctd Clear	Mog	M58	10000	18000-23000	11300-16800	3200-4300	65-70
	Ushio	E39	Clear	Mog	M80	9000	19000	N/A	5200	N/A
	Venture	ED28 T15	Clr/Ctd Clear	E39	M58	7500-10000	19000-23000	12400-15000	3000-5200	65-70
360	GE	ED37	Clr/Ctd	Mog	M59	20000	35000-39000	23000-27000	4000-4300	65-70
	Sylvania	BT37	Clr/Ctd	Mog	M59	V: 20000 H: 15000	V: 34500-36000 H: 30000	22500-23500 H: 19000	3600-4000	65-70
400	Eye	BT37 BT28 ED37	Clr/Ctd	Mog	M59	U: 20000 V: 20000-30000 H: 15000-20000	U: 35000-36000 V: 36000-42000 H: 32000-39000	U: 21000-24000 V: 28000-33000 H: 24800-30800	3800-4200	65-70
	GE	ED28 BT28 BT37 T15	Clr/Ctd Clr/Ctd Clr/Ctd Clear	Mog	M59	10000-20000	25000-44000	13300-31000	3000-6000	65-90
	Sylvania	BT28 BT37 ET18 T14.5	Clr/Ctd Clr/Ctd Clear Clear	Mog	M59	V: 20000 H: 15000	V: 33500-42000 H: 32000-33000	V: 22000-26000 H: 20500-21500	3200-5200	60-90
	Philips	ED28 ED37 R60 T15	Clear Clr/Ctd Clear Clear	Mog	M59	10000-20000	32500-40000	20800-27400	3200-4300	65-70
	Venture	ED28 ED37 T15	Clr/Ctd Clr/Ctd Clear	Mog	M59	10000-20000	32500-40000	21100-26000	3200-5200	65-70
1000	Eye	BT56 BT37	Clr/Ctd	Mog	M47	U: 12000 V: 12000 H: 9000	U: 99800-105000 V: 110000-120000 H: 105000-110000	U: 59900-66000 V: 86000-96600 H: 82000-86300	3400-4200	65-70
	GE	BT56 BT37	Clr/Ctd Clear	Mog	M47	V: 12000-15000 H: 9000-11000	V: 105000-115000 H: 96600-10500	V: 80000-90000 H: 73000-82000	3500-4000	65-80
	Sylvania	BT56 BT37	Clr/Ctd Clear	Mog	M47	V: 6000-18000	V: 100000-115000	V: 80000-96000	3400-4200	65-70
	Philips	BT37 BT56	Clear Clr/Ctd	Mog	M47	10000-12000	104500-120000	65800-83600	3400-3900	65-70
	Ushio	E39	Clr/Ctd	Mog	N/A	8000	N/A	N/A	10000	N/A
	Venture	BT56 BT37	Clr/Ctd Clear	Mog	M47	6000-12000	80000-115000	52000-86300	3400-5200	65-70

Table F-3: Product Availability: Probe-Start Metal Halide Lamp (3 of 3)

Rated Lamp Power(Watts)	Manufacturer	Bulb Designation	Coating	Base Type	ANSI Ballast Code	Lamp Life (Hours)	Initial Light Output (Lumens)	Mean Light Output (Lumens)	CCT (Kelvin)	CRI
1500	Eye	BT56	Clear	Mog	M48	3000	155000	140000	4000	65
	GE	BT56	Clear	Mog	M48	V: 3000-6000 H: 3000	V: 12000-178000 H: 155000-170000	V: 90000-160000 H: 130000-140000	3900-5200	65-80
	Sylvania	BT56	Clear	Mog	M48	3000-6000	V:150000-170000 H: 153000-155000	127500-140000	4000-4200	65-70
	Philips	BT56	Clear	Mog	M48	3000	165000	132000	3700	65
	Venture	BT56	Clear	Mog	M48	3000-6000	130000-165000	104000-137700	3400-5200	65-70
1650	GE	BT56	Clear	Mog	M112	3000	177000	145000	3200	65
	Venture	BT56	Clear	Mog	M112	3000	177000	145000	3200	70

Table F-4: Product Availability: Pulse-Start Metal Halide Lamp (1 of 2)

Rated Lamp Power(Watts)	Manufacturer	Bulb Designation	Coating	Base Type	ANSI Ballast Code	Lamp Life (Hours)	Initial Light Output (Lumens)	Mean Light Output (Lumens)	CCT (Kelvin)	CRI
32	GE	ED17	Coated	Med	M100	10000	2400	1700	3200	70
50	GE	ED17 BD17	Clr/Ctd	Med	M110	5000-10000	2900-3900	1500-2200	3200-4000	70-75
	Sylvania	E17	Clr/Ctd	Med	M110	V: 15000 H: 10000	3200-3450	1750-2000	2900-3000	70
	Venture	ED17	Clr/Ctd	Med	M110	V: 10000 H: 7500	V: 3000-3400 H: 2700-3100	V: 2000-2200 H: 1800-2000	3200-4000	65-70
70	GE	ED17 BD17	Clr/Ctd	Med	M98	12000	4500-5500	2800-3500	3200-4000	70-75
	Sylvania	E17 PAR38	Clr/Ctd Clear	Med	M98	V: 7500-15000 H: 6000-10000	4700-5500	3100-4000	2900-4200	75-82
	Venture	ED17 ED28	Clr/Ctd Clear	Med Mog	M98	V: 15000 H: 11250	V: 5000-5600 H: 4500-5000	V: 3300-3600 H: 3000-3300	2700-4000	65-70
100	GE	ED17 BD17	Clr/Ctd	Med	M90	15000	7600-9000	4900-6200	3200-4000	70-75
	Sylvania	E17 PAR38	Clr/Ctd Clear	Med	M90	V: 7500-15000 H: 6000-10000	7700-8500	5525-7500	2900-4200	75-82
	Venture	ED17 ED28	Clr/Ctd Clr/Ctd	Med Mog	M90	V: 15000 H: 11250	V: 8100-9000 H: 7300-8100	V: 5300-5900 H: 4800-5300	2700-4000	65-70
150	GE	ED17 BD17	Clr/Ctd	Med	M102	15000	11200-12500	7700-8600	3200-4000	70-75
	Sylvania	E17 PAR38	Clr/Ctd Clear	Med	M102	V: 7500-15000 H: 6000-10000	11500-12900	9000-11000	2900-4200	75-88
	Venture	ED17 ED28	Clr/Ctd	Med Mog	M102	V: 15000 H: 11250	V: 12600-14000 H: 11300-12600	V: 9500-10500 H: 8500-9500	2700-4000	65-70
175	GE	ED23.5 BD17	Clr/Ctd	Mog Med	M137	15000	16000-17500	12000-13000	3200-4000	65-75
	Philips	ED28	Clear	Mog	M137	15000	16000	11200	3900	65
	Venture	ED17 ED28	Clr/Ctd	Med Mog	M137	15000	16600-17500	13300-14000	3700-4000	65-70
200	Venture	ED17 ED28	Clr/Ctd	Med Mog	M136	12000-15000	19000-21000	15200-16800	3200-4000	65-70
250	GE	ED28	Clr/Ctd	Mog	M138	15000-20000	21500-23000	15500-17000	3900-4200	65
	Sylvania	BT28	Clr/Ctd	Mog	M138	15000	21500-23000	17200-19200	3600-4200	65-70
	Philips	ED28	Clear	Mog	M138	15000	23800	16600	4000	65
	Venture	ED28	Clr/Ctd	Mog	M138	15000	22600-25000	18100-20000	3700-4000	65-70
320	GE	ED28	Clr/Ctd	Mog	M132	20000	30000-34000	16500-25000	3700-4000	65-70
	Sylvania	BT28	Clr/Ctd	Mog	M131	V: 20000 H: 15000-20000	V: 28500-32000 H: 28000-33500	V: 19000-21000 H: 18400-24000	3800-4300	65-70
	Philips	ED28	Clr/Ctd	Mog	M132	20000	30100-31700	21500-23140	3600-3900	65-70
	Venture	ED28 ED37	Clr/Ctd	Mog	M132	15000-20000+	27900-34000	22300-27200	3200-4000	65-70

Table F-4: Product Availability: Pulse-Start Metal Halide Lamp (2 of 2)

Rated Lamp Power(Watts)	Manufacturer	Bulb Designation	Coating	Base Type	ANSI Ballast Code	Lamp Life (Hours)	Initial Light Output (Lumens)	Mean Light Output (Lumens)	CCT (Kelvin)	CRI
350	GE	ED37	Clr/Ctd	Mog	M131	20000-30000	33400-37000	23500-27500	3400-4000	62-70
	Sylvania	BT28 BT37	Clr/Ctd	Mog	M131 M132 M135	V: 20000 H: 20000	V: 28500-33000 H: 31500-40000	V: 19000-24500 H: 22000-29500	3300-4300	65-70
	Philips	ED37	Clr/Ctd	Mog	M131	20000	35000-37000	26250-28000	3700-4000	65-70
	Venture	ED28 ED37	Clr/Ctd	Mog	M131	15000-20000+	31700-37000	25400-29600	3200-4000	65-70
400	GE	ED37	Clr/Ctd	Mog	M135	20000-30000	40000-44000	28000-33000	3700-4000	65-70
	Sylvania	BT37	Clr/Ctd	Mog	M131	20000	4200-42000	23000-32800	3500-4000	65-70
	Philips	ED37	Clr/Ctd	Mog	M128	20000	37000-44000	24050-31000	3700-3900	66-70
	Venture	ED28 ED37	Clear	Mog	M135	15000-30000	37800-44000	30200-35200	3700-4000	65-70
450	Venture	ED37	Clr/Ctd	Mog	M144	20000+	45200-50000	36200-40000	3700-4000	65-70
750	GE	BT37	Clr/Ctd	Mog	M149	16000	72000-82000	54000-60000	3700-4000	65-70
	Sylvania	BT37	Clear	Mog	M149	V: 16000 H: 12000	V: 80000 H: 68000	V: 60000 H: 51000	4200	65
1000	Philips	BT37	Clear	Mog	M141	15000	120000	96000	3800	65
	Sylvania	BT37	Clear	Mog	M149	V: 15000 H: 9000	V: 110000 H: 107800	V: 96000 H: 86300	3800	65

Table F-5: Product Availability: Ceramic Metal Halide Lamps

Rated Lamp Power(Watts)	Manufacturer	Bulb Designation	Coating	Base Type	ANSI Ballast Code	Lamp Life (Hours)	Initial Light Output (Lumens)	Mean Light Output (Lumens)	CCT (Kelvin)	CRI
39	GE	PAR20 PAR30L		Med	M130	9000-10000	3400	2400-2600	3000	>80
	Sylvania	PAR20 PAR30L		Med	M130	9000	V: 3300	2640-2720	2900-3000	82-85
	Philips	PAR20 PAR30L		Med	M130	9000-12000	2000-3400	1600-2805	3000	81
50	Philips	ED17P ED17	Clear Clr/Ctd	Med	M110 M148	10000-15000	3560-4250	2600-3200	3000-4000	82-90
70	GE	PAR30L PAR38 BD17		Med	M85 M98 M139	9000-15000	5100-7000	4300-5600	3000-4200	>80 >90
	Sylvania	E17 PAR30L PAR38	Clr/Ctd Clear Clear	Med	M98	9000-12000	V: 5500-6600 H: 6300	4400-5280	2900-4200	83-90
	Philips	PAR30L PAR38 ED17 ED17P		Med	M98	6000-15000	6000-6600	4800-5440	3000-4000	82-92
100	GE	PAR38 BD17		Med	M90 M140	10000	8700-9200	6300-6600	3000	>80
	Sylvania	E17 PAR38	Clr/Ctd Clear	Med	M90	12000	8500-9000	6900-7200	3000	85
	Philips	PAR38 ED17 ED17P ED28	Clear Clr/Ctd Clr/Ctd Clear	Med	M90 M140	10000-15000	7500-9300	6375-7500	3000-4100	85-93
150	Sylvania	E17	Clr/Ctd	Med	M142	9000-12000	12700-14000	10800-12200	3000-4200	85-90
	Philips	ED17 ED17P	Clr/Ctd Clr/Ctd	Med	M142	6000-15000	11500-14200	8750-11360	3000-4200	85-96
400	Philips	ED37	Clr/Ctd	EEM	M128 M135	20000	34000-37000	28900-31450	3700-4000	90

Table F-6: Product Availability: Direct Replacement Metal Halide Lamps

Rated Lamp Power(Watts)	Manufacturer	Bulb Designation	Coating	Base Type	ANSI Ballast Code	Lamp Life (Hours)	Initial Light Output (Lumens)	Mean Light Output (Lumens)	CCT (Kelvin)	CRI
250	Eye	T15	Clear	Mog	H37	9000	18200	14000	6500	90
325	GE	ED37	Clr/Ctd	Mog	H33	V: 20000 H: 10000	V: 26300-28000 H: 24200-25800	V: 12900-13300 H: 11800-12200	3700-4000	65-70
400	Eye	T15 T17	Clear	Mog	H33	9000	29000-32000	20000-24000	6500	90
	GE	ED37	Clr/Ctd	Mog	H33	V: 15000 H: 10000	V: 35000-36000 H: 32200-33100	V: 21000-24000 H: 19300-22100	3700-4000	65-70
950	GE	BT56	Coated	Mog	H36	12000	100000	62900	3800	65

Table F-7: Product Availability: High-Pressure Sodium Lamps (1 of 2)

Rated Lamp Power(Watts)	Manufacturer	Bulb Designation	Coating	Base Type	ANSI Ballast Code	Lamp Life (Hours)	Initial Light Output (Lumens)	Mean Light Output (Lumens)	CCT (Kelvin)	CRI
35	Eye	ED17	Clr/Diff	Med	S76	24000+	2150-2250	1935-2025	2100	21
	GE	B17	Clr/Diff	Med	S76	16000	2150-2250	1935-2025	1900	22
	Sylvania	E17	Clr/Diff	Med	S76	16000+	2100-2250	1935-2050	1900	22
	Philips	ED17	Clr/Diff	Med	S76	24000+	2150-2250	1935-2025	2100	20
50	Eye	ED17 ED23.5	Clr/Diff	Med Mog	S68	24000+	3800-4000	3420-3600	1900-2100	21
	GE	B17 ED23.5	Clr/Diff	Med Mog	S68	24000+	3800-4000	3420-3600	1900	22
	Sylvania	ET23.5 E17	Clr/Diff	Mog Med	S68	24000-30000	3700-4000	3420-3600	1900	22
	Philips	ED17 ED23.5	Clr/Diff	Med Mog	S68	10000-24000+	2350-4000	2000-3600	2100-2700	21-85
70	Eye	ED17 ED23.5	Clr/Diff	Med Mog	S62	24000+	5860-6300	5270-5670	1900-2100	21
	GE	B17 ED23.5	Clr/Diff	Med Mog	S62	10000-40000	3800-6400	3040-5670	1900-2200	22-65
	Sylvania	ET23.5 E17	Clr/Diff	Mog Med	S62	24000-40000	5500-6300	4900-5600	1900-2150	22
	Philips	ED17 ED23.5 PAR38	Clr/Diff Clr/Diff Clear	Med Mog Med	S62	24000+	5860-6300	5270-5670	2100-2200	21-60
100	Eye	ED17 ED23.5	Clr/Diff	Med Mog	S54	24000+	8800-9500	7920-8550	2100	21
	GE	B17 ED23.5	Clr/Diff	Med Mog	S54	24000-40000	8800-10500	7920-9450	2000	22-23
	Sylvania	ET23.5 E17	Clr/Diff	Mog Med	S54	24000-40000	8800-9800	7500-8550	2100-2150	22
	Philips	ED17 ED23.5	Clr/Diff	Med Mog	S54	10000-24000+	4900-9500	4170-8550	2100-2700	21-85
150	Eye	ED17 ED23.5	Clr/Diff	Med Mog	S55	24000+	15000-16000	13500-14400	2100	21
	GE	B17 ED23.5 ED28	Clr/Diff Clr/Diff Clear	Med Mog Mog	S55 S56	15000-40000	10500-16000	9135-14400	2000-2200	22-65
	Sylvania	ET23.5 E17 BT28	Clr/Diff Clr/Diff Clear	Mog Med Mog	S55 S56	24000-40000	12500-16000	12100-14400	2100-2200	22
	Philips	ED17 ED23.5 ED28	Clr/Diff Clr/Diff Clear	Med Mog Mog	S55 S56	15000-24000+	11000-16000	9900-14400	2100-2200	21-60

Table F-7: Product Availability: High-Pressure Sodium Lamps (2 of 2)

Rated Lamp Power(Watts)	Manufacturer	Bulb Designation	Coating	Base Type	ANSI Ballast Code	Lamp Life (Hours)	Initial Light Output (Lumens)	Mean Light Output (Lumens)	CCT (Kelvin)	CRI
200	Eye	ED18	Clear	Mog	S66	24000+	22000	19800	2100	21
	GE	ED18	Clear	Mog	S66	24000-40000	21500-22000	18150-19800	2000-2100	22
	Sylvania	ET18	Clear	Mog	S66	24000-40000	21500-22000	18000-19800	2100	22
	Philips	ED18	Clear	Mog	S66	24000+	22000	19800	2100	21
225	Philips	ED18	Clear	Mog	S50	24000+	27500	24800	2100	21
250	Eye	ED18 ED37 ET18	Clear Diffuse Clear	Mog	S50	24000+	26000-28500	23400-25650	2100	21
	GE	ED18 ED28	Clear Diffuse	Mog	S50	15000-40000	22500-29000	20700-27500	2000-2200	22-65
	Sylvania	ET18 BT28	Clear Diffuse	Mog	S50	24000-40000	26000-29000	23200-26100	2100	22
	Philips	ED18 ED28	Clear Diffuse	Mog	S50	15000-24000+	23000-30000	20700-27000	2100-2200	21-65
310	GE	ED18	Clear	Mog	S67	24000+	37000	33300	2100	22
	Sylvania	ET18	Clear	Mog	S67	24000+	37000	33300	2100	22
	Philips	ED18	Clear	Mog	S67	24000+	37000	33300	2100	21
360	Philips	ED18	Clear	Mog	S51	24000+	47500	42800	2100	25
400	Eye	ED18 ED37 ET18	Clear Diffuse Clear	Mog	S51	24000+	47500-50000	42750-45000	2100	21
	GE	ED18 ED28 ED37	Clear Clear Diffuse	Mog	S51	15000-40000	37400-54000	34400-48600	2000-2200	22-70
	Sylvania	ET18 BT37	Clear Diffuse	Mog	S51	24000-40000	46000-50000	40000-45000	2100	21-22
	Philips	ED18 ED37	Clear Diffuse	Mog	S51	15000-24000+	37500-50000	33750-45000	2100-2200	21-65
430	Philips	ED18	Clear	Mog	S51	16000	53000	47700	2100	21
600	GE	T15	Clear	Mog	S106	12000+	90000	81000	2000	22
	Sylvania	T16	Clear	Mog	S106	24000	90000	81000	2200	22
	Philips	T14	Clear	Mog	S106	24000+	90000	81000	2100	21
750	GE	ED37	Clear	Mog	S111	24000+	110000	99000	2100	22
	Sylvania	BT37	Clear	Mog	S111	24000	105000	94500	2100	22
1000	Eye	E25	Clear	Mog	S52	24000+	140000- 145000	126000	2100	21
	GE	E25	Clear	Mog	S52	24000-40000	137500- 140000	115000-126000	2000-2100	22-25
	Sylvania	E25	Clear	Mog	S52	24000+	127000- 130000	11500-124000	2100	22
	Philips	ED37 E25	Clear	Mog	S52	24000+	125000- 140000	112000-126000	2100	21

Table F-8: Product Availability: Direct Replacement High-Pressure Sodium Lamps

Rated Lamp Power(Watts)	Manufacturer	Bulb Designation	Coating	Base Type	ANSI Ballast Code	Lamp Life (Hours)	Initial Light Output (Lumens)	Mean Light Output (Lumens)	CCT (Kelvin)	CRI
150	Eye	BT28	Clr/Diff	Mog	H39	24000	14500-15000	13200-13500	2100	25
	GE	ED28	Clear	Mog	H39	13000	12500	12000	1900	22
	Sylvania	BT28	Clear	Mog	H39	24000	11800	10600	1800	20
	Philips	ED28	Clear	Mog	H39	24000	15000	13500	1900	25
215	GE	ED28	Clear	Mog	H37	12000	20200	18600	1900	22
	Sylvania	BT28	Clear	Mog	H37	16000	20000	17000	2000	20
	Philips	ED28	Clear	Mog	H37	24000	23000	20700	1900	25
220	Eye	BT28	Clr/Diff	Mog	H37	24000	24500-25000	21800-22500	2100	25
300	Eye	BT37	Clr/Diff	Mog	H33	24000	37500-38000	33600-34000	2100	32
360	Eye	BT37	Clr/Diff	Mog	H33	24000	43000-45000	38700-40500	2100	26
	GE	BT37	Clear	Mog	H33	24000	45000	40500	2100	25
	Sylvania	BT37	Clear	Mog	H33	16000	36500	32800	2060	20
	Philips	ED37	Clear	Mog	H33	24000	45000	40500	1900	25
750	Eye	BT56	Clr/Diff	Mog	H36	24000	99500-100000	89400-90000	2100	36
880	Sylvania	E25	Clear	Mog	N/A	12000	101000	91000	2100	20
940	Eye	BT56	Clr/Diff	Mog	H36	24000	123000-130000	110700-117000	2100	26

Appendix G. Illuminating Engineering Society of North America Life-Cycle Cost and Payback Calculation Comparison

This section presents a comparison of the Life-Cycle Cost and Payback Period calculation methods presented in the IESNA Lighting Handbook, Ninth Edition (IESNA, 2000), Chapter 25, Lighting Economics, with the LCC and payback methods proposed by the Department for this draft framework.

G.1 Life-Cycle Cost

The Department's proposed LCC model calculates the LCC of an HID ballast and its initial and replacement lamps over the lifetime of the ballast. Therefore, the Department's LCC method is more complex than the example calculation presented in the IESNA Handbook, which calculates the LCC of a lamp. The Department's proposed calculation procedure is similar to that used in its LCC analysis of fluorescent lamp ballasts, in which both lamp and ballast costs were calculated over the lifetime of a ballast.

The following five points compare the Department's LCC method with the IESNA LCC method.

1. The equations for the present value of the operating costs are the same.

2. In the fluorescent ballast Technical Support Document (DOE, 2000), Chapter 4, Equation 4.1 is the general LCC equation where the operating costs can vary from year to year. This equation is in the LCC spreadsheet where the electricity prices change over time. Equation 4.1 is the same as equation 5.1, shown again below for reference:

$$LCC = P + \sum \frac{O_t}{(1 + r)^t} \qquad \text{(Equation 5.1)}$$

Where:

P = Total installed cost
Σ = Sum over analysis period
O_t = Annual operating cost
r = Discount rate for life cycle cost
t = Year (from 1 to lifetime)

3. Equation G.1 represents a special case where the operating cost (O_t) is constant every year. If operating costs are constant over time, Equation 5.1 simplifies to Equation G.1:

$$LCC = P + PWF * O_t \qquad \text{(Equation G.1)}$$

Where the PWF (Present Worth Factor) is represented by Equation G.2:

$$PWF = \frac{1}{r} * \left[1 - \frac{1}{1+r^N} \right] \qquad \text{(Equation G.2)}$$

Where:

PWF = Present Worth Factor
r = Discount rate for life cycle cost
N = Lifetime (in years)

Equation G.2 is equivalent to equation (25-5) in the IESNA Handbook, removing the A (amount of annual payment) on the right side of the IESNA equation.

$$P = A * \frac{(1+i)^y - 1}{i(1+i)^y} \qquad \text{(IESNA Equation 25-5)}$$

Where:

i = Discount rate for life cycle cost
y = Lifetime (in years)

Equations G.1 and G.2 are for illustration purpose and are not used in the LCC analyses, since the operating cost does vary by year in the analysis, according to the electricity price forecast.

4. The IESNA Handbook does not show an equation for the LCC that includes the installed cost. It does refer to the present value of the operating costs (over the lifetime). The IESNA Equations 25-8a to 25-8c show the calculation of the present value of the operating costs when the operating costs are escalating at a rate of k% per year. This only works when the escalation rate is constant over years, and will not work in this analysis, where the electricity prices vary by year. The general form of IESNA Equation 25-8a is:

$$P = \sum_{k=1}^{y} A \frac{(1+r)^k}{(1+i)^k} \qquad \text{(IESNA Equation 25-8a)}$$

Where:

P = Present worth, or amount at present (dollars)
A = Initial annual payment (dollars)
y = Number of years
i = Opportunity or interest rate
r = Rate of escalation, or percentage by which the annual payment increases each year, as decimal fraction (5% equals 0.05)

G.2 Payback Period

For the Payback Period calculation, the equation presented in the IESNA Handbook is a definition of payback period. The IESNA equation is:

$$P = \frac{I}{A} \qquad \text{(IESNA Equation 25-2)}$$

Where:

P = payback period (years)
I = incremental investment (dollars)
A = incremental annual cash flow

The incremental annual cash flow is the decreased annual operating costs. IESNA equation 25-2 is similar to Eqn. 5.3, the payback period equation in this document.

$$PB = -\frac{\Delta PC}{\Delta OC} \qquad \text{(Equation 5.3)}$$

Where:

PB = payback period (years)
PC = total initial purchase and installation cost (dollars)
OC = annual operating cost (dollars/year)

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